DOCUMENT RESUME

ED 192 153	CE 026 785
TITLE	Nuclear Technology Series. Course 35: Systems and Components.
INSTITUTION	Center for Occupational Research and Development, Inc., Waco, Tex.; Technical Education Research Center, Waco, Tex.
SPONS AGENCY	Office of Education (DHEW), Washington, D.C.
PUB DATE	Oct 80
CONTRACT	300-78-0582
NOTE	301p.; For related documents see CE 026 639-672, CE 026 779-780, CE 026 782-785, and CE 026 855-856.
AVAILABLE FROM	Center for Occupational Research and Development, 4800 Lakewood Dr., Suite 5, Waco, TX 76710 (Modules are available individually or by course; write for prices)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	Instrumentation Technicians; Learning Activities; Learning Modules; Nuclear Energy; Postsecondary Education; Quality Control; *Technical Education; Technical Occupations
IDENTIFIERS	*Control Systems (Mechanical); Nuclear Energy Occupations; *Nuclear Power Plants

ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Systems and Components, contains seven modules: Electrical Distribution, Instrumentation and Control for Major Plant Components, Recording and Display Devices, Process Control Loops and Devices, Cathode-Ray Tube Systems, Preventive Maintenance for Systems and Components, and Instrument Reliability. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter, exercises, materials, procedures, data tables, reference materials, and tests. (A master index and suggested program planning guides are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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ED192153

Nuclear Technology Series

COURSE 35

SYSTEMS AND COMPONENTS

CENTER FOR OCCUPATIONAL RESEARCH
AND DEVELOPMENT
4800 LAKEWOOD DRIVE
WACO, TEXAS 76710

CE 026 785

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

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OCT 1980

PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules – developed for use in two-year postsecondary technical institutions to prepare technicians for employment – are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert/experienced writer team and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Module Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Materials, which identify the equipment required to complete the laboratory procedure.

Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of the prestated objectives.

A helpful Index has been added at the end of each course.

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The Nuclear Technology Series consists of five curricula:

- Nuclear Reactor (Plant) Operator Trainee.
- Radiation Protection Technician.
- Nuclear Materials Processing Technician.
- Nuclear Quality-Assurance/Quality-Control Technician.
- Nuclear Instrumentation and Control Technician.

The completed Nuclear Technology Series consists of the following 35 technical specialty courses:

- Radiation Physics.
- Radiation Protection I.
- Principles of Process Instrumentation.
- Heat Transfer and Fluid Flow.
- Introduction to Nuclear Systems.
- Instrumentation and Control of Reactors and Plant Systems.
- Reactor Operations.
- Reactor Safety.
- Reactor Auxiliary Systems.
- Power Plant Systems.
- Radiation Detection and Measurement.
- Reactor Physics.
- Power Plant Chemistry.
- Introduction to Quality Assurance/Quality Control.
- Metallurgy and Metals Properties.
- Mechanical Component Characteristics and Specifications.
- Radiation Protection II.
- Radiological Emergencies.
- Radiation Shielding.
- Radiation Monitoring Techniques (Radiochemical).
- Radioactive Materials Disposal and Management.
- Advanced Radionuclide Analysis.
- Nuclear Chemical Processes.
- Nuclear Systems and Safety.
- Radioactive Material Handling Techniques.
- Nondestructive Examination (NDE) Techniques I.
- Metrology.
- Welding Inspection.
- Civil/Structural Inspection.
- Mechanical Inspection.
- Quality-Assurance Practices.
- Nondestructive Examination (NDE) Techniques II.
- Control Systems I.
- Control Systems II.
- Power Plant Electrical Systems and Components.

Availability: Instructional modules are available individually or by courses from:

Center for Occupational Research and Development
4800 Lakewood Drive, Suite 5
Waco, Texas 76710
Telephone (817) 772-8756

Printed:

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MODULE 35-6 Preventive Maintenance for Systems and Components

MODULE 35-7 Instrument Reliability

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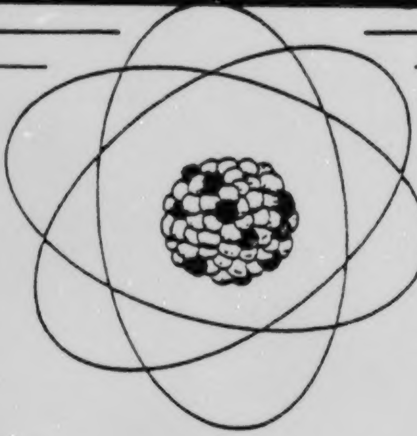
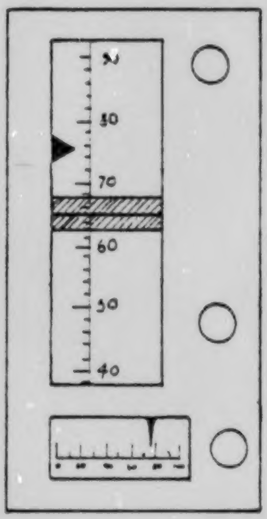
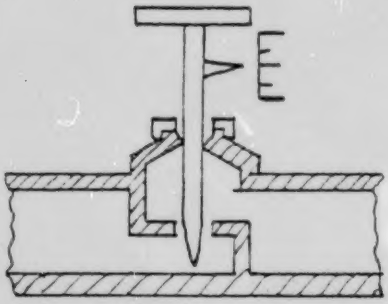


NUCLEAR TECHNOLOGY

MODULE 35-1

ELECTRICAL DISTRIBUTION





SYSTEMS AND COMPONENTS

COURSE 35

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

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COURSE 33 SYSTEMS AND COMPONENTS

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INTRODUCTION

A nuclear power plant designed to generate electricity requires much electrical equipment for its internal operation. Instrumentation and control circuitry, electrical motors, and lighting present a wide variety of electrical power requirements that must be met during normal and emergency conditions. A basic understanding of how these requirements are met by the electrical distribution system is necessary for the operator or technician to perform his or her job. This module discusses the components of a typical power plant's electrical distribution system and their operation.

MODULE PREREQUISITES

The student should have completed a course in Fundamentals of Electricity and Electronics; Course 5, "Introduction to Nuclear Systems"; and Course 6, "Instrumentation and Control of Reactors and Plant Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
    - Bus.
    - Circuit breaker.
    - Feeder.

Inverter.
Motor control center.
Motor starter.
Panelboard.
Relay.
Switchboard.
Switchgear.
Transformer.
Vital.

2. Define at least twelve symbols used for electrical distribution systems.
3. List and describe the locations at which major alternating currents and direct currents are utilized in a typical power plant system.
4. Using a typical diagram of a nuclear power plant electrical distribution system, trace through a given circuit, identifying all the major pieces of equipment and symbols.
5. Describe the following equipment and how each is employed in a nuclear power plant:
    Transformers.
    Switchgear.
    Motor control centers.
    Panelboards.
    Battery chargers.
6. Identify where a.c. and d.c. standby equipment is used in a nuclear power plant.
7. List the equipment that would be supplied by an engineered safety features service bus.
8. Define the purpose of an engineered safety features (ESF) service bus and the three ways it receives electrical power.

9. Describe a typical diesel generator system and how it is employed in a nuclear power plant.

ELECTRICAL DISTRIBUTION DEFINITIONS

The electrical distribution system of a power plant, like any other specific industry, is described by terms particular to its needs. Listed below are definitions of several of the more useful terms:

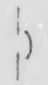
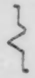
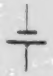
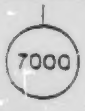
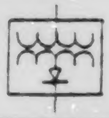
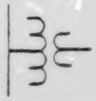
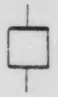
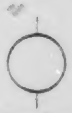
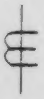
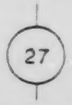
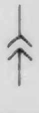
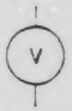
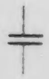
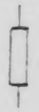
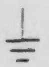
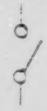
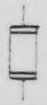
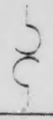
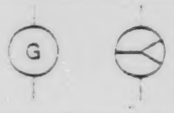
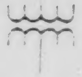
- A bus is the junction of three or more circuits to a copper or aluminum bar which is used for electrical current distribution.
- A circuit breaker is an electrical switch that can open or interrupt an electrical circuit when the current is too high or when the load it is supplying is to be turned off.
- A feeder is a wire or cable that conducts electricity from a source to a piece of equipment.
- An inverter is an electrical device that transforms direct current into alternating current.
- A motor control center is an assembly consisting of electrical bus, circuit breakers, and motor starters in a metal enclosure. It is used for the protection and operation of a collection of medium-voltage plant electrical equipment. Motor starters start and stop equipment.
- A motor starter is an electrical device, usually a magnetic contactor, for the starting and stopping of low-voltage equipment.
- A panelboard is an assembly of circuit breakers and/or fuses in a wall-mounted panel used for the protection and operation of a collection of low-voltage plant electrical equipment such as lighting or freeze-protection equipment.

- A relay is an electrical device that monitors the status of an electrical circuit for the detection of abnormal conditions.
- A switchboard is the same as a panelboard except that it is mounted on the floor with back access.
- Switchgear is an assembly that consists of an electrical bus, circuit breakers, relays, and metering equipment in a metal enclosure. It is used for the protection and operation of a collection of high- and medium-voltage electrical plant equipment. Starting and stopping of this equipment is accomplished with circuit breakers.
- Synchronism means "having identical period and phase."
- A transformer is an electrical device that changes alternating current from one voltage to another.
- The term "vital" refers to the power plant electrical equipment that must operate during a station blackout.

ELECTRICAL DISTRIBUTION SYMBOLS

Each industry has a shorthand method for use in diagrams, circuits, and systems to save the writing of long words each time the item appears. From the system of symbols used in electrical distribution, several of the more important ones are listed in Table 35-1-1.

TABLE 35-1-1. ELECTRICAL DISTRIBUTION SYMBOLS/DESCRIPTION.

Symbol	Description	Symbol	Description
	Air Circuit Breaker		Magnetic Overload Element or Actuating Coil
	Battery		Motor (Horsepower rating)
	Battery Charger		Potential Transformer
	Circuit Breaker		Relay or Meter Coil
	Current Transformer		Examples: Undervoltage relay
	Drawout Disconnect		Voltmeter
	Electrical Contact (open when device is in de-energized position)		Resistor
	Electrical Ground (earth)		Switch (shown in open position)
	Fuse		Thermal Overload Relay
	Generator		Transformer

ELECTRICAL POWER USAGE

Electrical equipment and circuits in a nuclear power plant can be divided into two groups – (1) equipment that uses alternating current (a.c.) electrical power and (2) equipment that uses direct current (d.c.) electrical power.

Alternating current is used by equipment listed below:

- Motors that drive fans, pumps, and valves.
- Normal plant lighting.
- Instrument and control equipment such as recorders, annunciators, and power supplies for control panels and circuit boards.
- Electric heaters.
- Battery chargers, which are the normal supply to the direct current system.
- Control rod drive mechanisms.
- Inverters – for the normal supply to the vital a.c. system.
- Plant computers.
- Freeze protection of valves and piping.
- Heat tracing of boric acid lines.
- Radiation monitoring equipment.
- Security equipment.
- Communication equipment.

However, direct current is used by such equipment as the following:

- Process instrumentation – electronic circuit boards and transmitters.
- Emergency plant lighting.
- Emergency pumps for backup in vital systems such as turbine lubrication oil and generator seal oil.

- Electrical distribution system – as control for opening and closing of circuit breakers and relays.
- Inverters for emergency supply to the vital a.c. system.
- Solenoid valves, which control air-operated control valves.

ELECTRICAL DISTRIBUTION VOLTAGES

The amount of electrical power required by a piece of equipment determines the voltage with which it can be operated most efficiently. The higher the power requirement, the higher the voltage should be. In a typical power plant, five or six different voltages are available for various equipment.

High-voltage a.c., usually 6900 volts and/or 4160 volts, is employed for loads greater than 400 horsepower. Such motors include those for the reactor coolant pumps, circulating water pumps, component cooling water pumps, safety injection pumps, and service water pumps.

Medium-voltage alternating current, usually 480 volts, powers motors from 1 horsepower to 400 horsepower, including those motors that drive the control room ventilation units, the motor-operated valves, and the instrument air compressors.

Low-voltage alternating current, 120 volts, is the normal supply for small loads such as plant lighting and process instrumentation.

Typical direct-current voltages are 125 volts and 250 volts for control power emergency lighting and emergency pumps. Direct-current voltages for control power to process instrumentation are 48 volts, 24 volts, and 12 volts.

HIGH-VOLTAGE A.C. SYSTEM

Nuclear power plants receive electrical power from a wide variety of sources: Such variety increases the reliability and availability of the plant's auxiliary equipment and, therefore, increases the reliability and availability of the plant itself. The utilities transmission system supplies a source of "startup" power to the plant's auxiliaries through a startup auxiliary transformer when the plant's turbine generator is not operating. Typically, a nuclear power plant has at least two separate and independent startup transformers to increase the availability of a power source for the plant's auxiliaries. A unit auxiliary transformer takes power from the plant's turbine generator when it is operating in order that the plant can supply its own auxiliary power. These large outdoor transformers are insulated and cooled by oil, which is circulated through the transformer windings and cooled by fans (Figure 35-1-1). Differential and overcurrent relays protect the auxiliary transformers from faults. Auxiliary transformers reduce the very high transmission or generator voltages to the level of the plant's high-voltage system.

Electrical power is distributed from the transformers to the high-voltage loads by the use of high-voltage switchgear. These loads include the plant's large motors (greater than 400 horsepower) and the medium-voltage stepdown transformers. The switchgear consists of a bus, to which the electrical loads are connected by circuit breakers (Figure 35-1-2). An operator can operate these circuit breakers remotely from a central control station to start or stop motors and other electrical loads. Ammeters and voltmeters are mounted locally on the switchgear and remotely on the central panels in order that the electrical status of the equipment can be monitored easily. Protection relays are connected to the incoming and outgoing feeders by current and potential transformers. If undervoltage, overvoltage, or overcurrent conditions are detected by these relays, they will trip their respective circuit breakers to isolate and protect the electrical device.

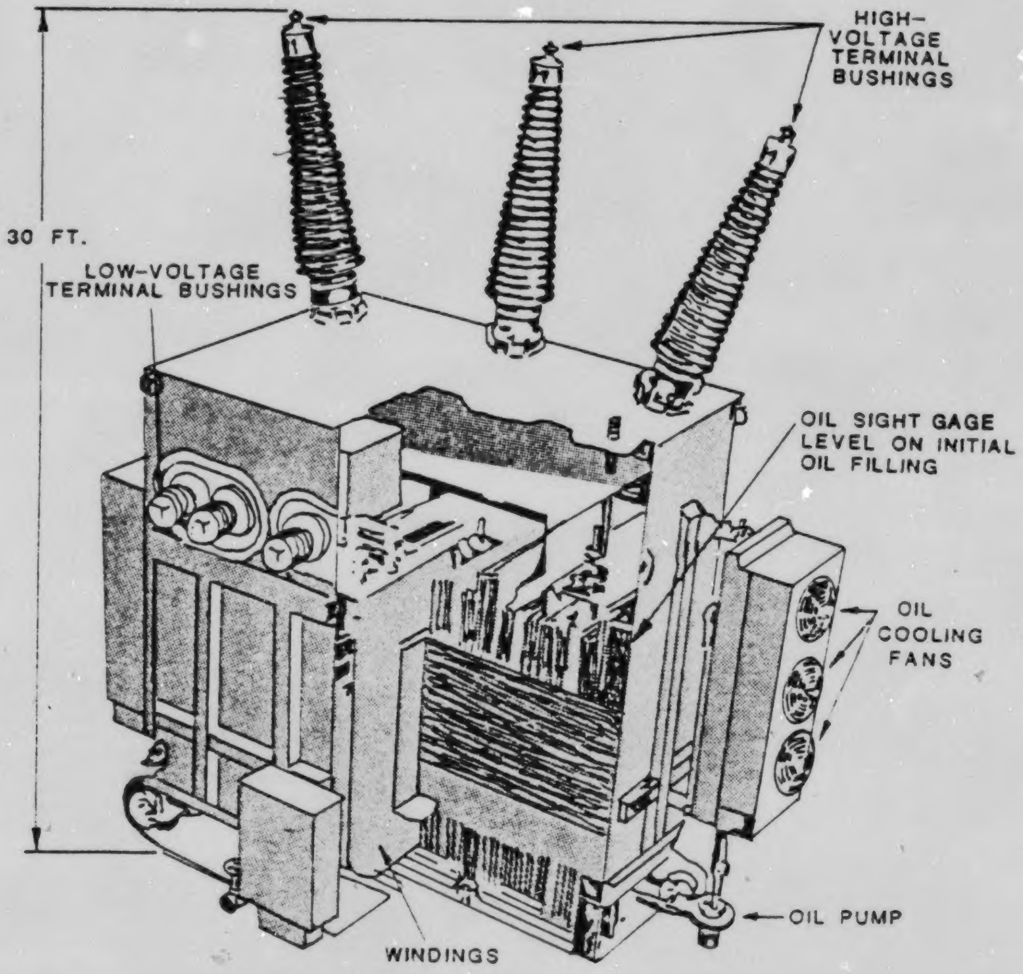

HIGH-VOLTAGE TERMINAL BUSHINGS
30 FT.
LOW-VOLTAGE TERMINAL BUSHINGS
OIL SIGHT GAGE LEVEL ON INITIAL OIL FILLING
OIL COOLING FANS
OIL PUMP
WINDINGS

Figure 35-1-1. Auxiliary power transformer.

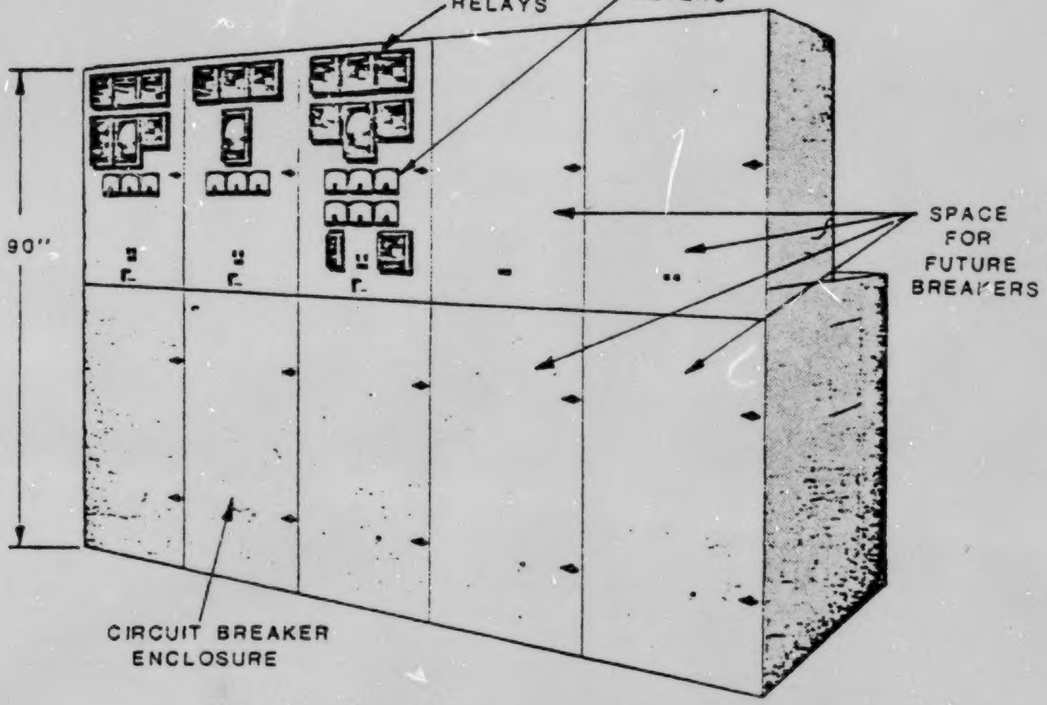


Figure 35-1-2. High-voltage a.c. switchgear.

In most plants, if the normal source of power is lost to the switchgear, then an "automatic transfer scheme" will open the normal source breaker. If the alternate source is available and in synchronism with the switchgear bus, the alternate breaker will close and will supply power to the switchgear. The operator can transfer load manually from one source to another at the central control station, by first turning on the synchroscope for the incoming source to ensure that the source is in snychronism with the switchgear bus. If it is, the operator operates a control switch to close the incoming breaker and then operates a switch to open the other breaker. If power is lost and transfer does not take place, the loads are shed automatically by the opening of the breakers. Figure 35-1-3 is a one-line diagram of a typical plant high-voltage system.

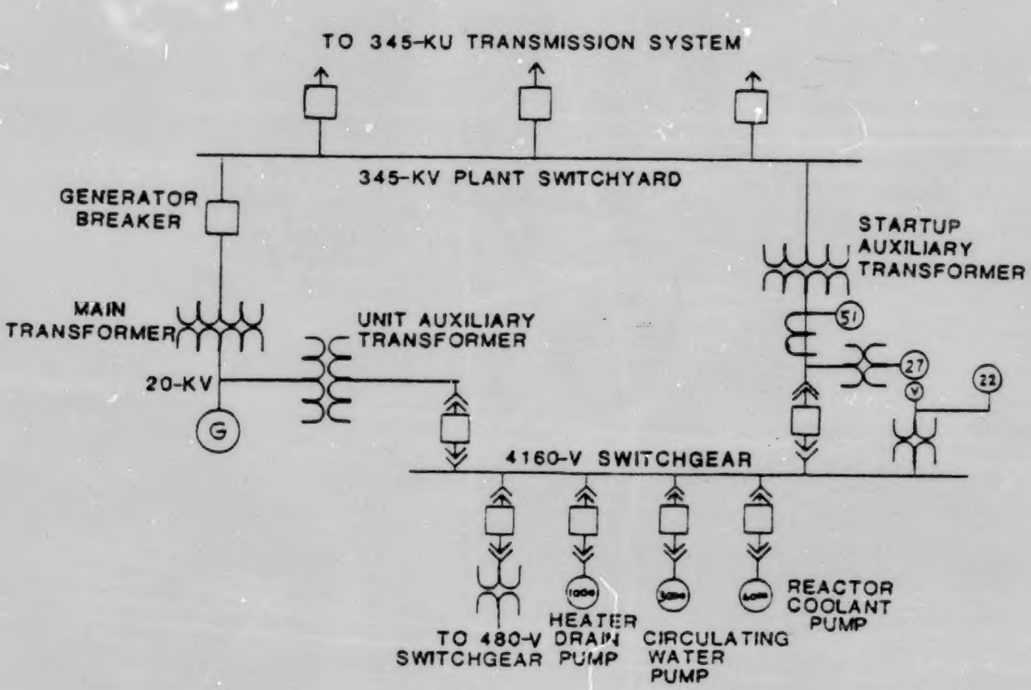

TO 345-KU TRANSMISSION SYSTEM
345-KV PLANT SWITCHYARD
GENERATOR BREAKER
STARTUP AUXILIARY TRANSFORMER
MAIN TRANSFORMER
UNIT AUXILIARY TRANSFORMER
51
27
22
V
20-KV
G
4160-V SWITCHGEAR
REACTOR COOLANT PUMP
HEATER DRAIN PUMP
TO 480-V SWITCHGEAR
CIRCULATING WATER PUMP

Figure 35-1-3. High-voltage a.c. distribution system.

MEDIUM-VOLTAGE A.C. SYSTEM

From the high-voltage switchgear, power is fed to dry-type air cooled transformers, where the voltage is stepped down (reduced) to the level of the plant's medium-voltage a.c. system. It then is fed to medium-voltage switchgear, which distributes the power to the larger medium-voltage loads such as pressurizer heaters, rod drives, motors (100 to 400 horsepower), and motor control centers. This switchgear has a bus, air circuit breakers, meters, relays, and controls similar to the high-voltage switchgear (Figure 35-1-4). Loads are started and stopped by the circuit breakers operated remotely from the central control station.

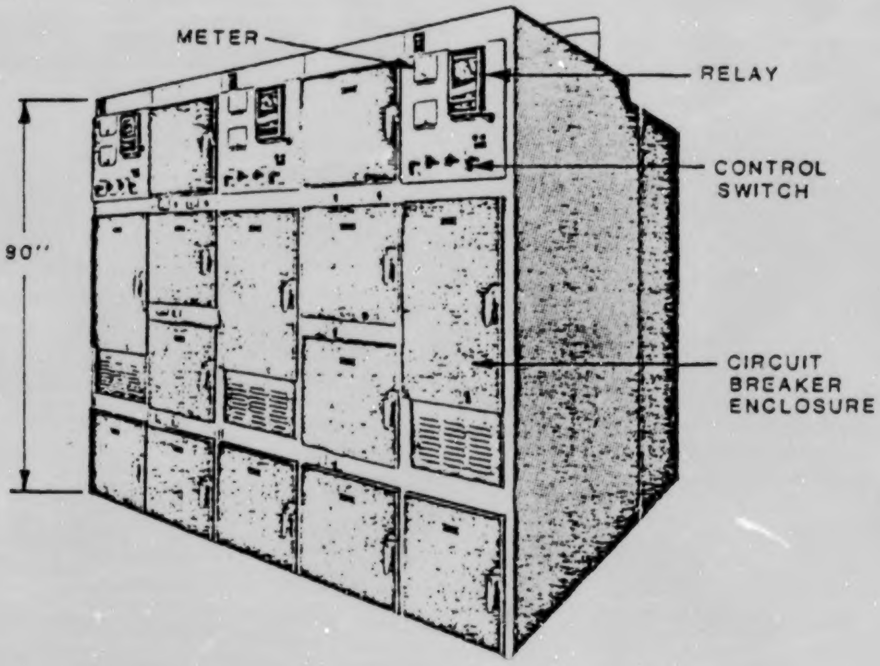


Figure 35-1-4. Medium-voltage a.c. switchgear.

Motor control centers (MCCs) are located throughout the plant in close proximity to the loads they feed (Figure 35-1-5). Since the vast majority of loads in the plant are fed by MCCs, this reduces the length of power cables required and increases operability. Motor control centers have a bus, circuit breakers, and motor starters. The circuit

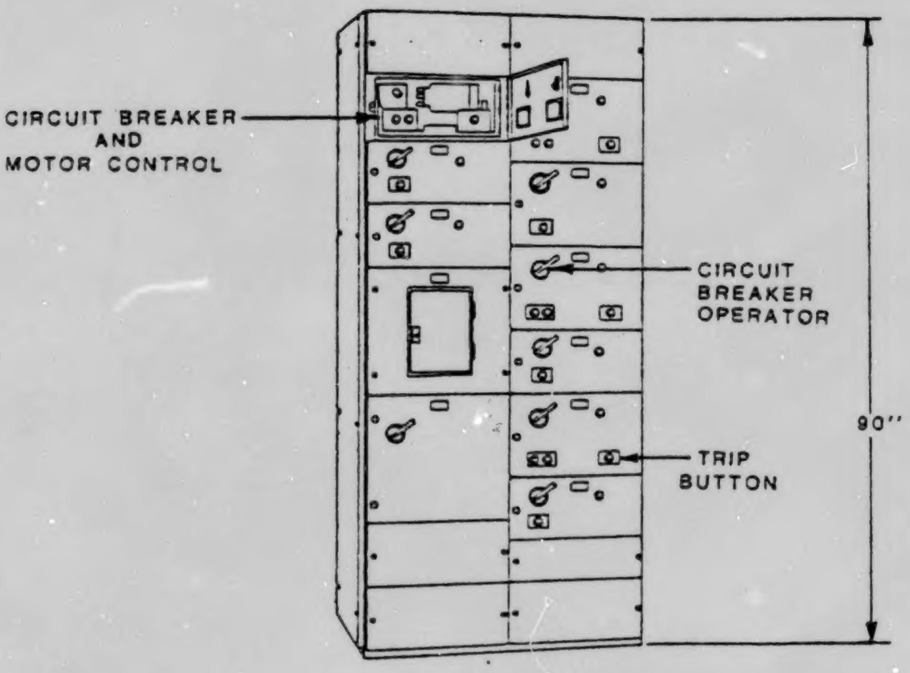


Figure 35-1-5. Motor control center.

breaker protects the load from damage due to a short circuit but is not used for normal on-off operation of the load. A motor starter is used for this purpose. The motor starter (a type of relay) receives its power downstream of the breaker. To turn a load on, the breaker must be closed. The relay then is energized either remotely at the central control station or locally at the motor control center. When energized, the relay contacts close and energize the load. Overload protection normally is provided by thermal relays, which will trip the starter relay and open the starter contacts when overheated by the overcurrent. Magnetic trip elements will protect against short-circuit currents by tripping the breaker. Motor control center loads include –

- Motors 100 hp or less.
- Battery chargers, which supply normal power to the direct-current distribution systems.
- Inverters, which supply normal power to the vital alternating-current systems.
- Transformers, which supply power to the low-voltage alternating-current system.

A diagram of a typical power plant's medium-voltage distribution system is presented in Figure 35-1-6.

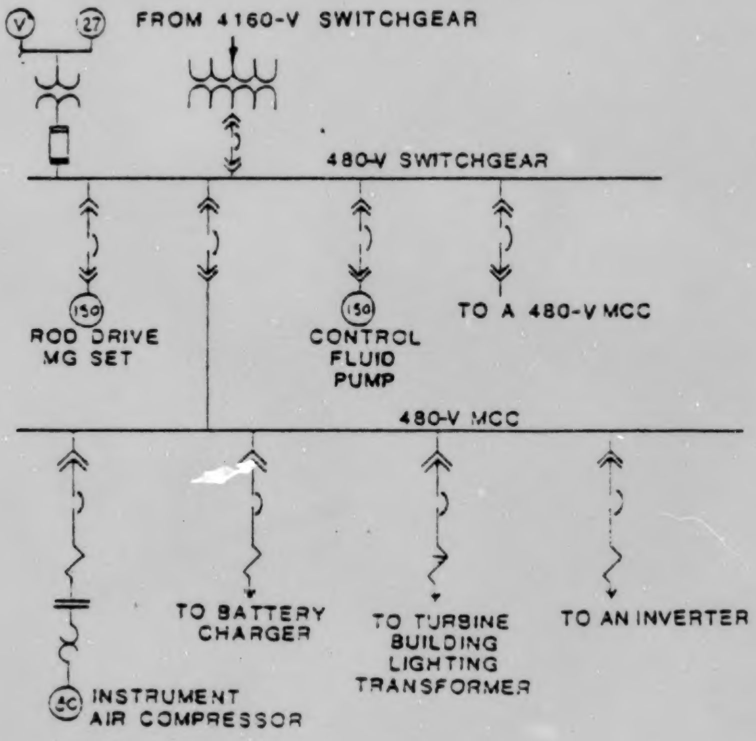

V
27
FROM 4160-V SWITCHGEAR
480-V SWITCHGEAR
150
ROD DRIVE MG SET
150
CONTROL FLUID PUMP
TO A 480-V MCC
480-V MCC
TO BATTERY CHARGER
TO TURBINE BUILDING LIGHTING TRANSFORMER
TO AN INVERTER
AC
INSTRUMENT AIR COMPRESSOR

Figure 35-1-6. Medium-voltage a.c. distribution system.

LOW-VOLTAGE A.C. SYSTEM

Power is fed from the medium-voltage motor control centers to stepdown transformers, which reduce the voltage to the level of the plant's low-voltage a.c. system. These transformers then feed a.c. panelboards, which distribute the power to the low-voltage loads (Figure 35-1-7). Panelboards similar to those in homes contain a bus and overcurrent devices (usually circuit breakers). These switch-type circuit breakers cannot be operated remotely. They protect the load from an overcurrent condition. The panelboards are located in close proximity to the loads they serve.

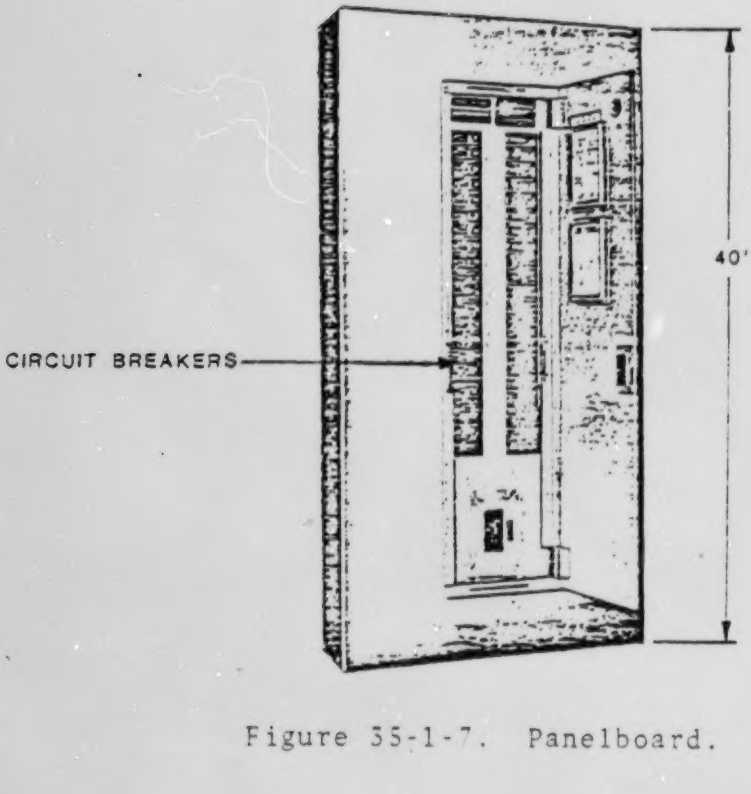


Figure 35-1-7. Panelboard.

Their loads include lighting, electrical outlets, heaters, and fractional-horsepower motors. A typical low-voltage transformer and panelboard one-line diagram is illustrated in Figure 35-1-8.

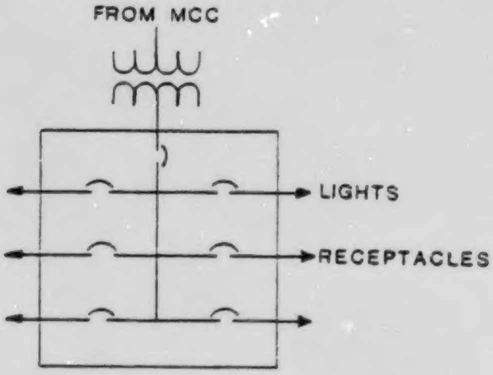


Figure 35-1-8. Low-voltage a.c. distribution system.

VITAL A.C. DISTRIBUTION SYSTEM

In any power plant, some loads are considered vital to the safe operation of the plant. A nuclear power plant with its added safety requirements has even more loads that must be operable at all times; therefore, an uninterruptible power supply is required and usually is provided in the form of an inverter. Normally, an inverter is fed by a medium-voltage a.c. motor control center. The voltage is stepped down and rectified to direct current, which is sent to the inverter to be converted to a regulated, low-voltage, alternating current. From the inverter, power is fed to panelboards. If the normal supply is lost, power is fed from the plant d.c. system through a blocking diode to the input of the inverter. This arrangement results in an uninterruptible power source. Equipment fed by this uninterruptible supply includes:

- Computers.
- Radiation monitoring systems.
- Nuclear instrumentation systems.
- Reactor protection system.
- Security system.
- Main control board.

Figure 35-1-9 shows a typical vital a.c. system.

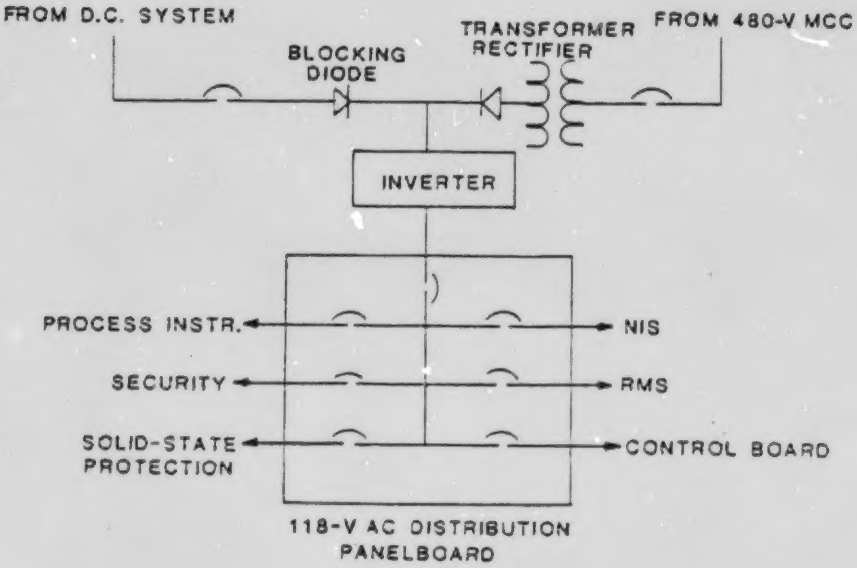

FROM D.C. SYSTEM
BLOCKING DIODE
TRANSFORMER RECTIFIER
FROM 480-V MCC
INVERTER
PROCESS INSTR.
NIS
SECURITY
RMS
SOLID-STATE PROTECTION
CONTROL BOARD
118-V AC DISTRIBUTION PANELBOARD

Figure 35-1-9. Vital a.c. system.

DIRECT CURRENT DISTRIBUTION SYSTEM

Equipment that uses direct current in a nuclear power plant is served by several d.c. distribution systems of different voltages (Figure 35-1-10). However, they all have the same basic equipment: batteries, battery chargers, d.c. switchboards, and d.c. panelboards. The batteries consist of several wet-cells connected in series (Figure 35-1-11). A 125/250 volt system contains 120 battery cells, which are quite large and usually take up one or more rooms since they

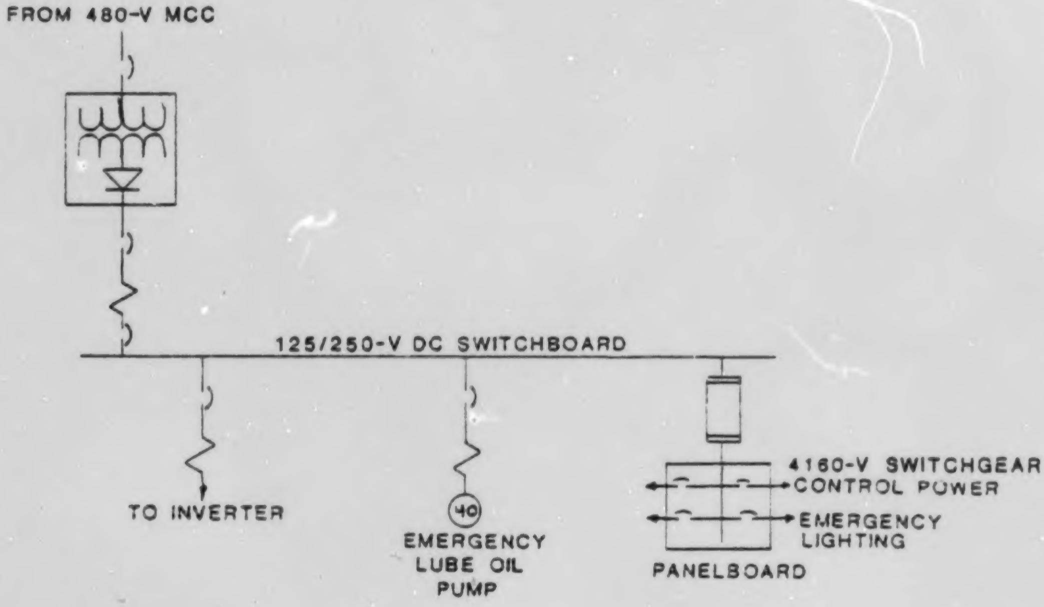

FROM 480-V MCC
125/250-V DC SWITCHBOARD
TO INVERTER
40
EMERGENCY
LUBE OIL
PUMP
4160-V SWITCHGEAR
CONTROL POWER
EMERGENCY
LIGHTING
PANELBOARD

Figure 35-1-10. Direct current distribution system.

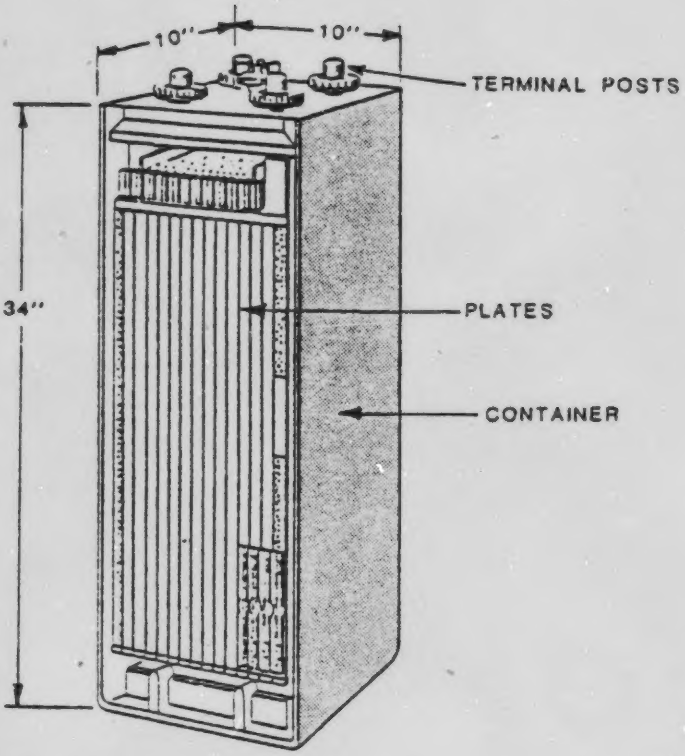


Figure 35-1-11. Battery cell.

have the most and the largest loads. Battery chargers rectify the medium-voltage a.c. from the motor control centers. The battery chargers and batteries are connected to a switchboard. Normally, the battery chargers will supply power to the d.c. system while they keep the batteries on float charge. However, if a.c. power is lost, the batteries will pick up the load. The d.c. switchboard includes a bus, circuit breakers, fuses, meters, and voltage relays. The panelboards are similar to the a.c. panelboards. Direct-current loads include –

- Standby emergency lighting.
- Control power.
- Standby emergency pumps.

ENGINEERED SAFETY FEATURES

A nuclear plant is unique when compared to other power plants because it contains equipment that must operate in the most adverse conditions, including earthquakes, nuclear accidents, and loss of all offsite power (which is called a "blackout"). To provide power for this equipment, a nuclear power plant's electrical distribution system is divided into two separate systems. Each of these systems is equipped with all the electrical subsystems mentioned previously. A "normal" system serves the loads, such as circulating water pumps, not required in a nuclear accident or a blackout. An "Engineered Safety Features" (ESF) system supplies power to the equipment that might be required in a nuclear accident or in a blackout. ESF loads include the following:

- The emergency core-cooling system.
- Service water pumps.
- Component-cooling water pumps.
- Auxiliary feedwater pumps.
- Containment spray pumps.

To ensure that one component failure will not prevent the ESF equipment from operating when needed, the ESF system is divided into two or three separate and independent systems termed "trains." In order to increase availability, each "train" is supplied by two sources of power – preferred and alternate – usually accomplished by two separate transformers supplied by the offsite electrical transmission system.

The preferred source supplies power to the ESF system during all operating conditions – startup, shutdown, normal, and emergency. If the preferred source is lost due to a transformer fault or transmission line disturbance, the system automatically transfers from the preferred source to the alternate source. Each train has all the equipment needed to shut down the unit safely.

Since the ESF system is required to operate in a blackout or earthquake, it must have an emergency supply of power other than the offsite electrical transmission system. Diesel generators are the source of this standby emergency power. Each "train" is equipped with a diesel generator, which is started when the preferred and alternate sources of offsite power are lost, thus providing a third source of power. These diesel generators, though quite large, must be automatically started, accelerated to full speed and voltage, and be ready to accept load in 8 to 10 seconds. Air compressors normally are used to force compressed air into the cylinders to start the diesel generators.

If the diesel generator is needed and if it is up to speed and voltage, the feeder breaker for the generator closes. ESF loads then are sequenced onto the bus by means of a safeguards sequencer. The sequencer prevents the starting current of the loads from overloading the diesel generator. The loads that would be sequenced to "on" in a blackout are different from the loads that would be sequenced "on" in a nuclear accident. In a blackout, the normal cooling systems, such as service water and component cooling water, are very important. In an accident, the emergency core-cooling system is most important and, therefore, is sequenced on first. A typical ESF bus is illustrated in Figure 35-1-12.

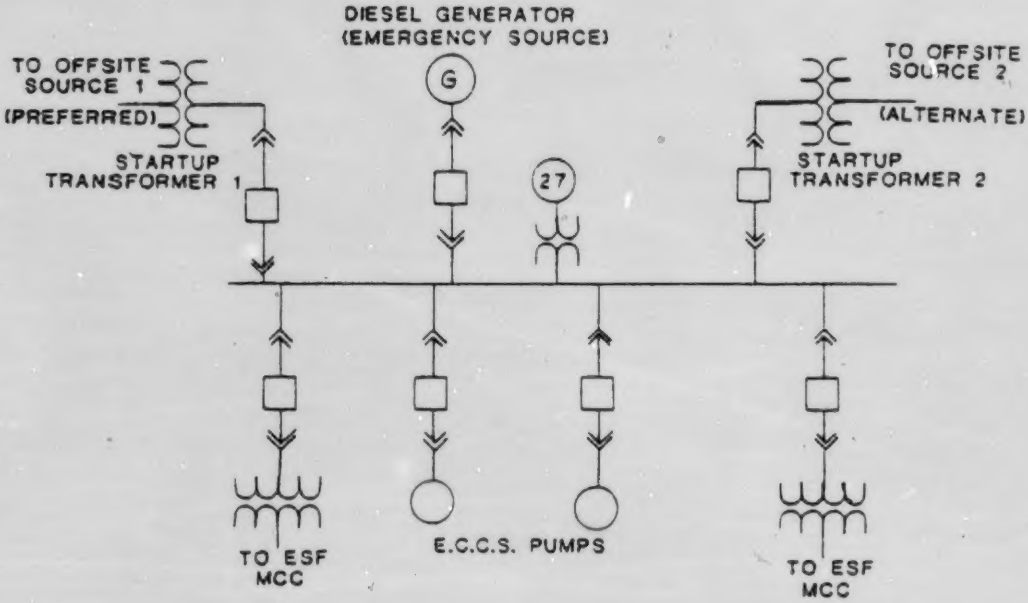

DIESEL GENERATOR
(EMERGENCY SOURCE)
G
TO OFFSITE SOURCE 1
(PREFERRED)
STARTUP TRANSFORMER 1
27
TO OFFSITE SOURCE 2
(ALTERNATE)
STARTUP TRANSFORMER 2
TO ESF MCC
E.C.C.S. PUMPS
TO ESF MCC

Figure 35-1-12. Engineered safety features bus.

ELECTRICAL POWER CABLE

The electrical distribution system and loads are connected to each other by electrical power cables. Power cables are run throughout the plant in cable trays and conduit and are grouped by the voltage signal they carry. Typically, the cable grouping is as follows:

- High voltage.
- Medium voltage.
- Low voltage.
- Instrument signal and d.c.

There is separation between cable trays that carry power to the different trains. In the event of fire, destruction of one train's cable tray would not affect the operation of the other train.

The typical power plant electrical distribution system in Figure 35-1-13 is made up of all the systems previously discussed.

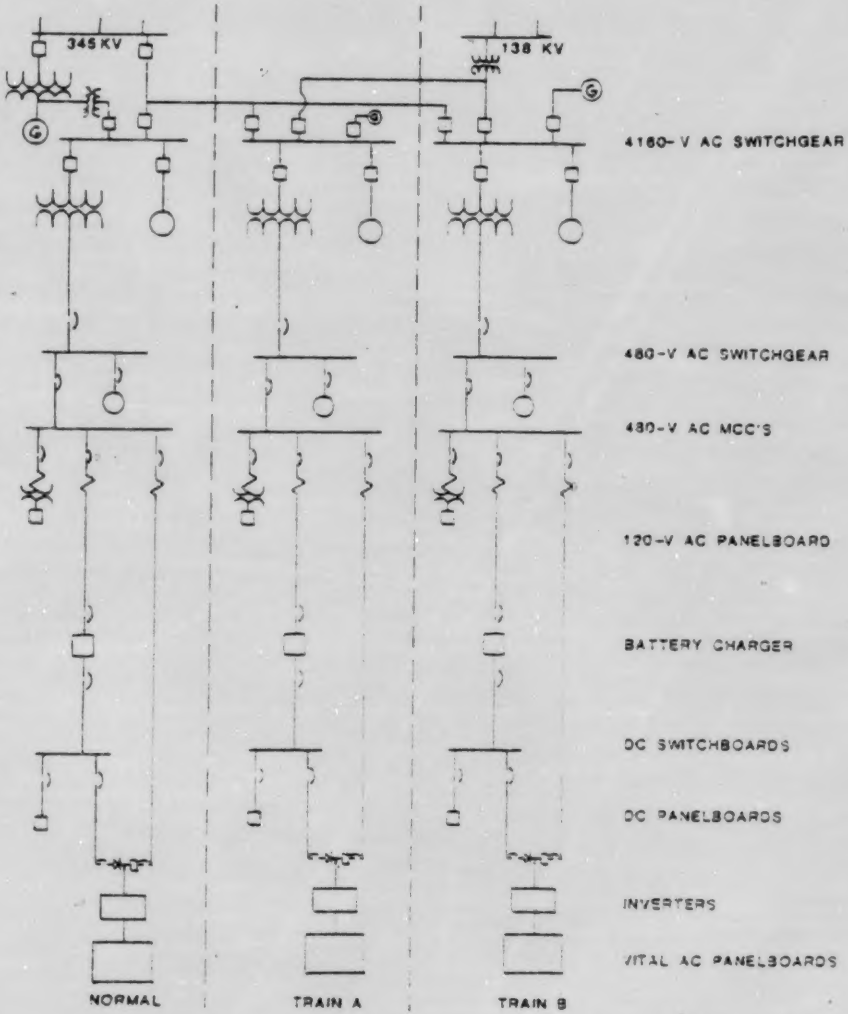
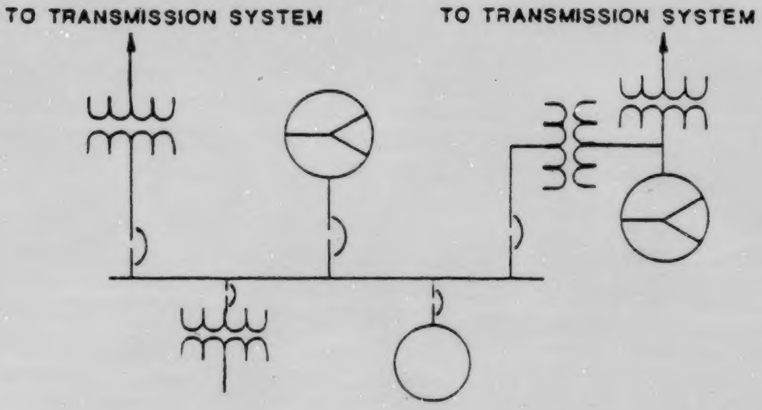

345 KV
138 KV
4160-V AC SWITCHGEAR
480-V AC SWITCHGEAR
480-V AC MCC'S
120-V AC PANELBOARD
BATTERY CHARGER
DC SWITCHBOARDS
DC PANELBOARDS
INVERTERS
VITAL AC PANELBOARDS
NORMAL
TRAIN A
TRAIN B

Figure 35-1-13. Typical electrical distribution system of a nuclear plant.

EXERCISES

1. Label each of the symbols in the following circuit.


TO TRANSMISSION SYSTEM
TO TRANSMISSION SYSTEM

2. Draw a circuit of a distribution system that consists of a battery, a battery charger, a d.c. switchboard, and a d.c. motor.
3. Draw a diagram of a circuit that would be used to protect and to operate a 50-hp motor.

MATERIALS

None.

PROCEDURES

FIELD TRIP TO A POWER PLANT

Schools may have difficulty in visiting a nuclear power plant; however, most of the same equipment may be found at a local electrical power plant, school power plant, or industrial power plant. Therefore –

1. Arrangements should be made to visit an electrical power plant and to locate the electrical distribution equipment listed below.
    - Auxiliary transformer.
    - High-voltage switchgear.
    - Medium-voltage switchgear.
    - Motor control center.
    - Low-voltage panelboard.
    - Battery.
    - Battery charger.
    - Diesel generator.
2. Describe how each piece of equipment operates, and draw a diagram that illustrates how this equipment fits into the plant's electrical distribution system.

DATA TABLES

None.

REFERENCE MATERIALS

Fink, Donald G. Standard Handbook for Electrical Engineers. New York: McGraw-Hill Book Company, 1968.

Smeaton, Robert W. Switchgear and Control Handbook. New York: McGraw-Hill Book Company, 1977.

Westinghouse Electric Corporation. Westinghouse Electrical Maintenance Hints. Strafford, PA: Westinghouse Electric Corp., 1974.

TEST

1. Match the correct answer in Column B to the question in Column A by placing the alphabetical designation in the parentheses ( ).

Column A

( ) Bus.
( ) Circuit breaker.
( ) Feeder.
( ) Inverter.
( ) Motor control center.
( ) Motor starter.
( ) Panelboard.
( ) Relay.
( ) Switchboard.
( ) Switchgear.
( ) Synchronism.
( ) Transformer.
( ) Vital.

Column B

A. Electrical device that transforms direct current into alternating current.

B. Junction of three or more circuits to a copper or aluminum bar used for electrical current distribution.

C. Electrical device that changes alternating current from one voltage to another.

D. Electrical device, usually a magnetic contactor, used for the starting and stopping of low-voltage equipment.

E. Electrical device that monitors the status of an electrical circuit for the detection of abnormal conditions.

F. Electrical switch that can open or interrupt an electrical circuit when the current is too high or when the load it is supplying is to be turned off.

G. An assembly of an electrical bus, circuit breakers, and motor starters in a metal enclosure. It is employed for the protection and operation of a collection of medium-voltage plant electrical equipment. Motor starters start and stop the equipment.

H. Assembly of an electrical bus, circuit breakers, relays, and metering equipment in a metal enclosure. It is for the protection and operation of a collection of high- and medium-voltage electrical plant equipment. Circuit breakers are utilized for the starting and stopping of this equipment.

I. Power plant equipment that must operate during a station blackout.

J. Wire or cable that conducts electricity from a source to a piece of equipment.

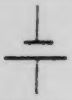
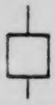
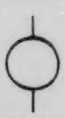
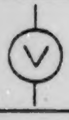
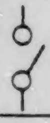
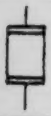
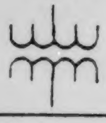
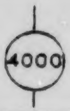
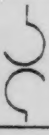
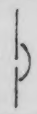
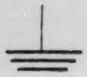
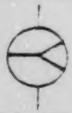
K. Assembly of circuit breakers and/or fuses in a wall-mounted panel employed for the protection and operation of a collection of low-voltage plant electrical equipment such as lighting or freeze-protection equipment.

L. Having identical period and phase.

M. Equipment that uses alternating and direct current to power the batteries.

N. Switchgear provided to control the electrical thermostats.

2. Write the description of each of the following electrical distribution symbols in the space on the following page.

SYMBOL	DESCRIPTION
	
	
	
	
	
	
	
	
	
	
	
	

3. Describe where major alternating currents and direct currents are utilized in a typical power plant system.

4. Listed below are five pieces of nuclear power plant equipment. Describe each of them, explaining how each is used in the plant.
    a. Transformers.

    b. Switchgear.

    c. Motor control centers.

d. Panelboards.

e. Battery chargers.

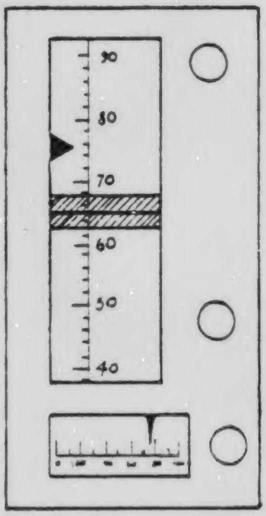
5. Explain where a.c. and d.c standby equipment is utilized in a nuclear power plant.

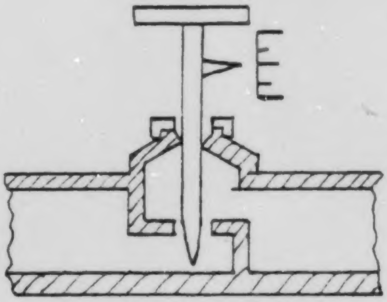
6. List below the equipment that would be supplied by an engineering safety features service bus.

NUCLEAR TECHNOLOGY

MODULE 35-2

INSTRUMENTATION AND CONTROL FOR MAJOR PLANT COMPONENTS





SYSTEMS AND COMPONENTS

COURSE 35

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

CONTENTS

COURSE 35 SYSTEMS AND COMPONENTS

MODULE 35-1 Electrical Distribution
⇨ MODULE 35-2 Instrumentation and Control for Major Plant Components
MODULE 35-3 Recording and Display Devices
MODULE 35-4 Process Control Loops and Devices
MODULE 35-5 Cathode-Ray Tube Systems (CRT)
MODULE 35-6 Preventive Maintenance for Systems and Components
MODULE 35-7 Instrument Reliability

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INTRODUCTION

Instrumentation and control systems provide the capability to monitor, alarm, and control (manually or automatically) process parameters as well as mechanical equipment associated with the process. Such systems also provide for the protection of process equipment. In addition, these systems enhance the integrated operation of plant process systems and mechanical equipment in the production of end products such as electricity, chemicals, and fuels.

Instrumentation and control systems consist of one or more channels, sometimes referred to as "loops," each of which consists of several basic components, as illustrated in Figure 35-2-1.

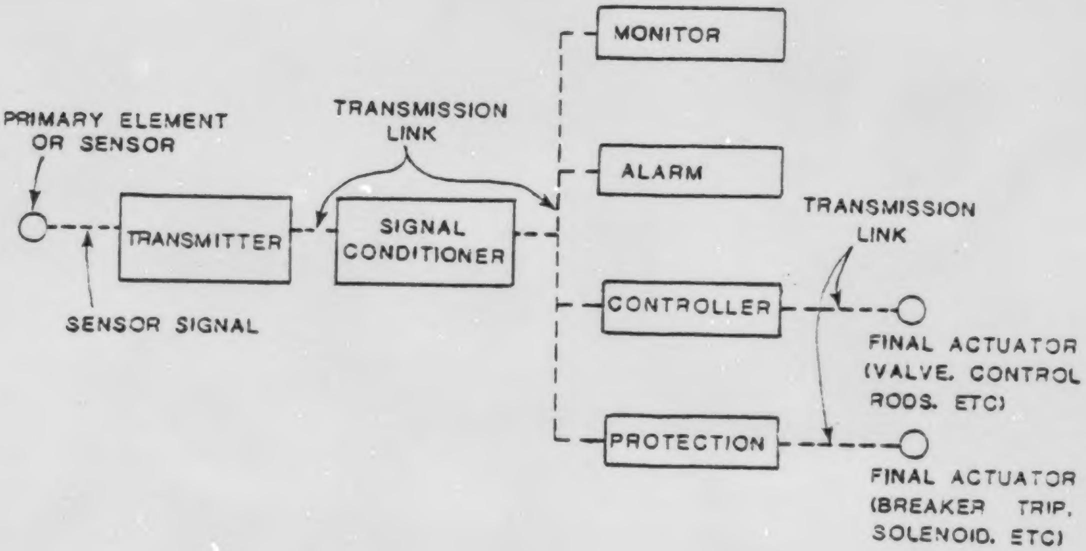

PRIMARY ELEMENT OR SENSOR
TRANSMISSION LINK
MONITOR
ALARM
TRANSMITTER
SIGNAL CONDITIONER
TRANSMISSION LINK
SENSOR SIGNAL
CONTROLLER
FINAL ACTUATOR (VALVE, CONTROL RODS, ETC)
PROTECTION
FINAL ACTUATOR (BREAKER TRIP, SOLENOID, ETC)

Figure 35-2-1. Basic instrumentation and control system.

The sensor, or primary element, is the principal building block of any given channel. The transmitter and signal conditioner provide the means by which the sensor signal is converted to a more practical process signal. This signal is then used, either singly or in conjunction with other process signals; to monitor a process; to alarm abnormal conditions; to protect mechanical equipment from damaging conditions; or to control plant process systems through control of the final actuator.

The sensor signal and transmission link may be electronic, pneumatic, or mechanical, or a combination of these. However modern instrumentation and control systems usually are based upon electronic signaling; therefore, the systems covered in this module are heavily based on electronic signaling.

Each functional block of the system may also be electronic, pneumatic, or mechanical, or a combination of these, with some type of supply appropriate to each type. For pneumatic applications, the supply normally is instrument air; but for electronic applications, the supply is an electronic power supply. No such supply is used for mechanical applications since this type of signal conversion and transmission is accomplished by mechanical linkages.

This module discusses the basic instrumentation and control systems of the following as applied to a PWR nuclear power plant:

- Main turbine-generator.
- Reactor control.
- Steam generator level.
- Pressurizer pressure.
- Boron measurement of reactor coolant.

Module 35-4 discusses in further detail the instrumentation and control of two systems covered in this module.

MODULE PREREQUISITES

The student should have completed Course 3, "Principles of Process Instrumentation"; Course 5, "Introduction to Nuclear Systems"; Course 6, "Instrumentation and Control of Reactors and Plant Systems"; Course 10, "Power Plant Systems"; Course 33, "Control Systems I"; and Course 34, "Control Systems II."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
    - EHC.
    - Signal conditioner.
    - PMG.
    - T_{avg}.
    - T_{ref}.
    - RTD.
    - NIS.
    - M/A.
    - D/P.
2. Sketch the block diagrams for the following instrumentation and control systems:
    - Main turbine-generator.
    - Reactor control.
    - Steam generator level.
    - Pressurizer pressure.
    - Boron measurement of reactor coolant.
3. Describe the function of each block and the type of signal conversion and transmission used for those systems listed in Objective 2.

4. Identify the different channels (or loops) of each system listed in Objective 2.
5. Discuss where each block may be typically located in a nuclear power plant.
6. Identify the equipment that typically houses each block(s).

MAIN TURBINE-GENERATOR

In the generation of electricity, three main parameters are measured to obtain the sequential control of the main turbine and generator. These parameters form the basis of the main turbine-generator instrumentation and control system and are as follows:

- Turbine speed.
- Generator load.
- Network voltage.

Other parameters measured specifically for equipment protection include —

- Vibration.
- Stress.
- Temperature.

Figure 35-2-2 illustrates a basic turbine-generator instrumentation and control system.

The speed channel consists of the speed sensor, the signal conditioner, and the load controller and is used in the turbine speed control mode. This channel does not utilize a transmitter because the sensor signal strength is sufficient for rapid transmission to the signal conditioner from its remote location. The signal conditioner then converts the sensor signal to a usable signal from proportional to turbine speed. The speed signal then is compared to a reference speed signal selected from the operator panel. A speed error signal, developed in the controller, is used to position the steam valve through the control of the servo-actuator. The servo-actuator serves to convert the electronic signal to a hydraulic signal that is proportional to valve-position demand. The hydraulic system pro-

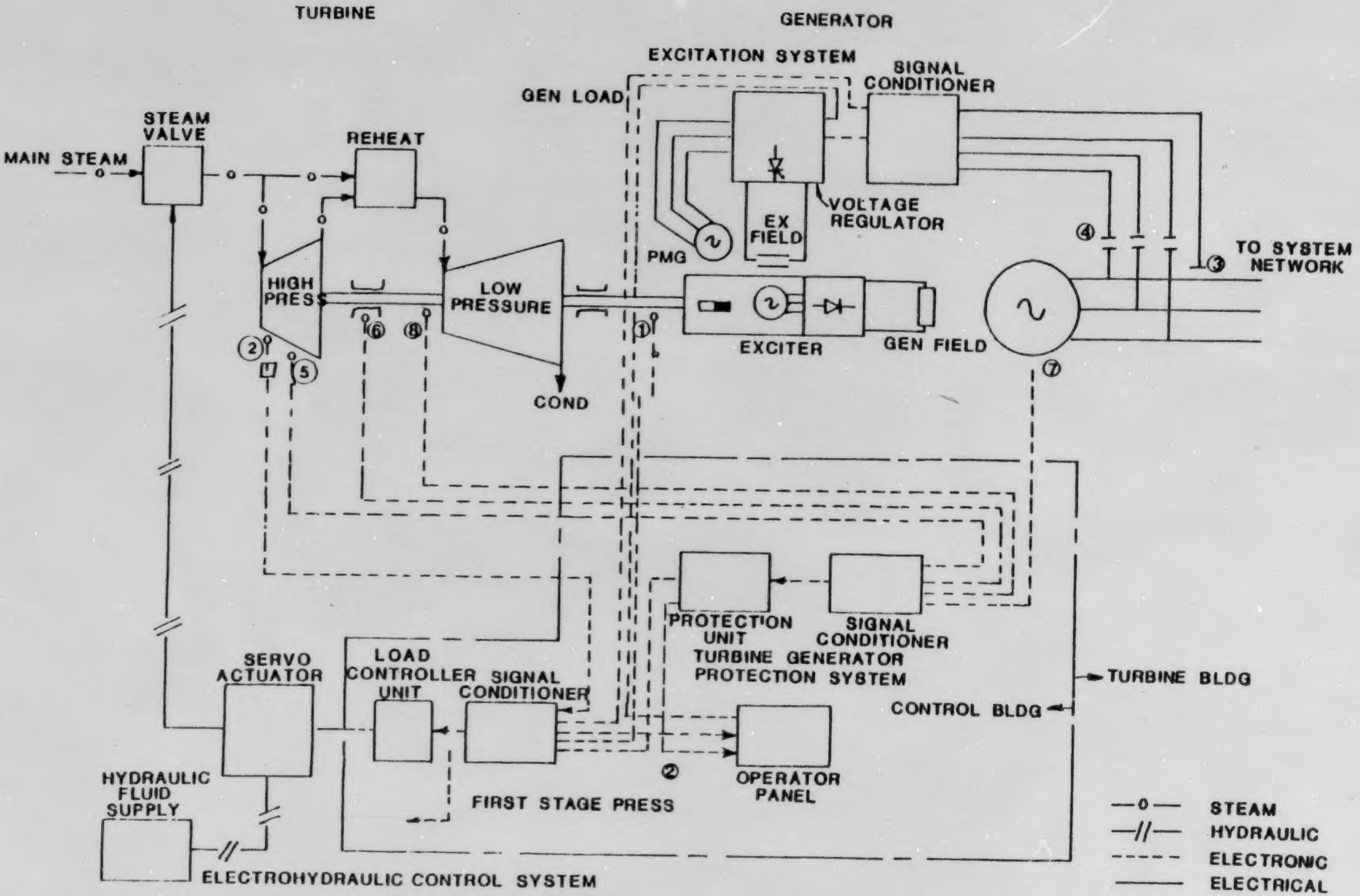

TURBINE
GENERATOR
EXCITATION SYSTEM
SIGNAL CONDITIONER
GEN LOAD
STEAM VALVE
MAIN STEAM
REHEAT
VOLTAGE REGULATOR
EX FIELD
PMG
④
③ TO SYSTEM NETWORK
HIGH PRESS
LOW PRESSURE
②
⑤
⑥
⑧
①
EXCITER
GEN FIELD
⑦
COND
PROTECTION UNIT
SIGNAL CONDITIONER
TURBINE GENERATOR PROTECTION SYSTEM
SERVO ACTUATOR
LOAD CONTROLLER UNIT
SIGNAL CONDITIONER
TURBINE BLDG
CONTROL BLDG
②
OPERATOR PANEL
HYDRAULIC FLUID SUPPLY
FIRST STAGE PRESS
ELECTROHYDRAULIC CONTROL SYSTEM
—o— STEAM
—//— HYDRAULIC
- - - - ELECTRONIC
—— ELECTRICAL

Figure 35-2-2. Turbine-generator system.

vides the force that opens the steam valve. This electro-hydraulic control system is commonly known as the EHC.

The turbine first stage pressure channel consists of an integral pressure sensor-transmitter (2) and a signal conditioner, providing a bias signal to the load controller (speed controller) when the turbine-generator is in the load control mode. The signal conditioner converts the pressure-sensor signal to a signal of common range and units as used throughout the controller and is directly proportional to turbine first-stage pressure. The first-stage pressure signal is also used by reactor and steam generator level-control systems which will be discussed later in this module.

Two other channels are associated with the load controller: The speed channel, mentioned previously, provides a turbine speed bias to compensate for rapid load changes. The main signal used by the load controller, however, is the generator load.

Generator load is measured from generator output current and voltage as parameters of operation. Current and voltage channels consist of current and voltage transducers (3 and 4), respectively, which provide the load signal through use of a signal conditioner. At the output of the signal conditioner, the load channel begins and provides input into the load controller.

The generator load then is compared to a reference load signal selected at the operator's panel. The load error signal developed in the controller then is used to position the steam valve through the control action of a servo-actuator. Generator load control is used only during on-line operation.

Generator output voltage is regulated by control of the generator field voltage. Control is accomplished by a voltage regulator and generator field exciter.

Current and voltage channel signals (covered previously) are used by the voltage regulator as feedback signals. These signals are compared to a reference setpoint by the load controller, which regulates the actuation of thyristors for the final excitation of the generator field.

In Figure 35-2-2, the permanent magnetic generator (PMG) provides the supply necessary to excite the generator main exciter stator windings, which, in turn, generate the d.c. current for the generator field windings. The exciter illustrated is known as a "brushless exciter."

Parameters most commonly measured for the protection of the turbine-generator are temperature (5, 6, and 7) and vibration (8). Signals provided by these channels are conditioned and supplied to the protection unit (Figure 35-2-2). Signals derived from the protection unit serve to bias the steam-valve actuation (in the case of turbine stress protection); to alarm high vibration or bearing temperatures or generator stator winding hot spots; and to initiate turbine and generator breaker trips when these parameters exceed a predetermined limit.

Turbine stress protection is provided by the measurement of a differential temperature gradient developed in the metal of the turbine shell between the high-pressure steam inside and the ambient air temperature outside during heatup. This protection avoids cracking of the turbine shell during cold turbine startups.

Hot spots in generator stator windings are determined by measurement of winding temperatures throughout the stator. Several temperature sensors are located within the stator to provide this capability. Hot spots are located by the highest temperatures measured in the respective areas of the stator. Generator output and magnitude of the hot spots determine when generator protection is actuated by the trip of the generator breaker.

All parameters measured, as shown on Figure 35-2-2, are monitored at the operator panel (control board) by strip recorders, dial indicators, or computer printouts. These indications provide the capability for the human interface in the control scheme and will be presented in several successive modules.

REACTOR CONTROL

During normal power operation, the reactor is controlled by a programmed average temperature of the reactor coolant and by regulation of core reactivity. Such control allows the main steam pressure to be held at optimum operating conditions and is accomplished by a combination of two methods:

- Variation of the reactor coolant boron concentration.
- Selective positioning of the control rods.

Instrumentation and control associated with the rod control system will be covered in this section since reactor control by the use of boron was discussed in a previous course. These two methods, however, are used in conjunction with control reactivity.

The control system consists of two error signals, the sum of which provides the inputs into the rod control system. These error signals are generated by the deviation of actual reactor coolant average temperature (T_{avg}) from the programmed average temperature (T_{ref}), and the mismatch between turbine load rate and nuclear power rate. (See Figure 35-2-3).

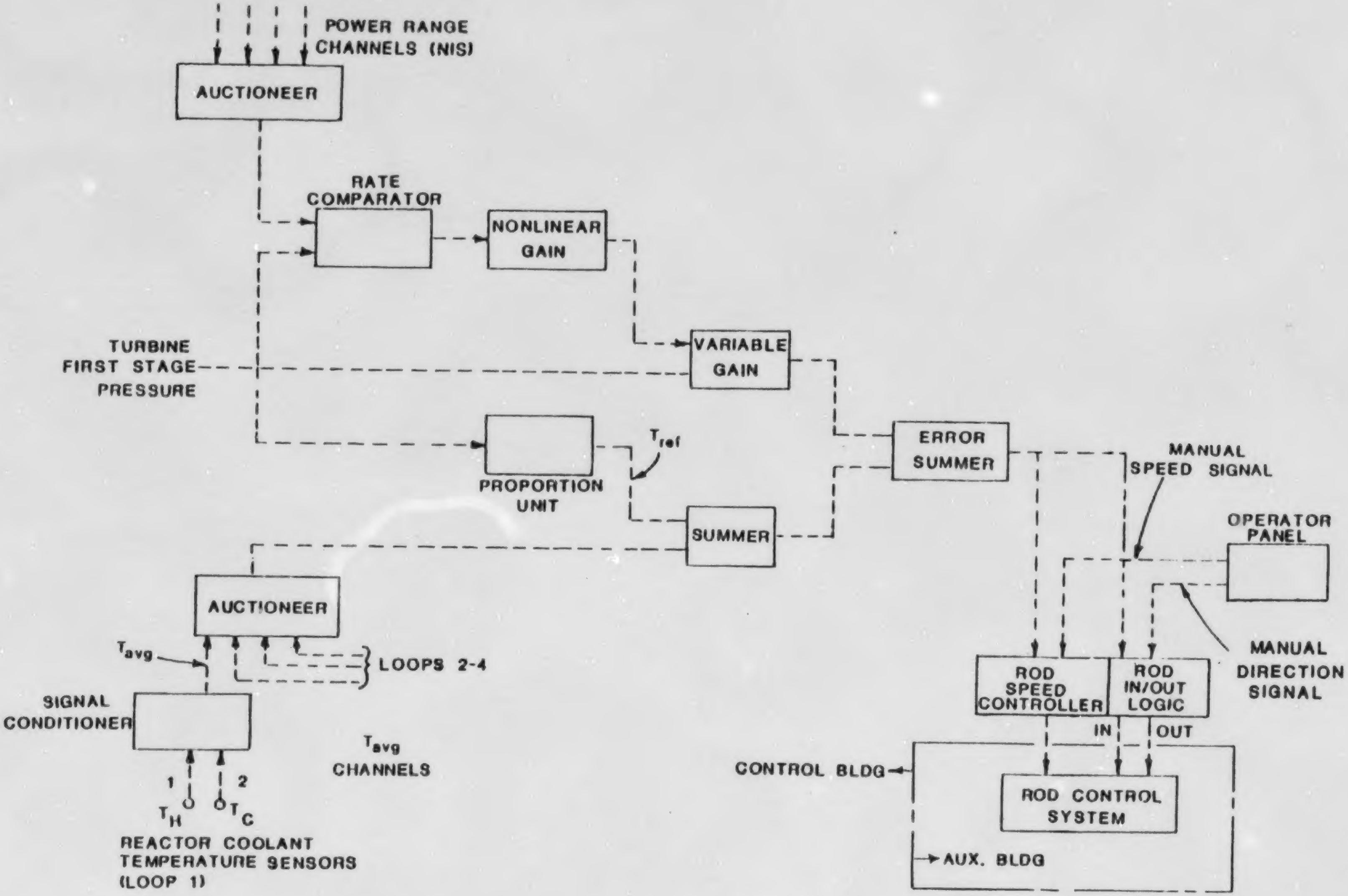

POWER RANGE CHANNELS (NIS)
AUCTIONEER
RATE COMPARATOR
NONLINEAR GAIN
TURBINE FIRST STAGE PRESSURE
VARIABLE GAIN
ERROR SUMMER
PROPORTION UNIT
T_{ref}
SUMMER
MANUAL SPEED SIGNAL
OPERATOR PANEL
AUCTIONEER
T_{avg}
LOOPS 2-4
SIGNAL CONDITIONER
T_{avg} CHANNELS
1
2
T_H
T_C
REACTOR COOLANT TEMPERATURE SENSORS (LOOP 1)
MANUAL DIRECTION SIGNAL
ROD SPEED CONTROLLER
ROD IN/OUT LOGIC
IN
OUT
CONTROL BLDG
ROD CONTROL SYSTEM
AUX. BLDG

Figure 35-2-3. Reactor control system.

The T_{avg} channels consist of two temperature sensors-per channel (1 and 2), which measure reactor coolant temperature in both the hot (T_H) and cold (T_C) legs of the system. No transmitters are associated with this channel because these sensors usually are resistance temperature detectors (RTDs) powered by the signal conditioner.

T_{avg} is provided at the output of each T_{avg} channel signal conditioner; then all values are "auctioneered" (selected) for the highest average temperature. The highest T_{avg} then is compared with T_{ref} at the associated channel summer. T_{ref} is directly proportional, within limits, to turbine first-stage pressure, a signal obtained from the first stage pressure channel of the turbine-generator instrumentation and control system. T_{ref} (programmed average temperature) is provided at the output of the proportional unit.

The summer (an electronic adding-or-subtracting device) compares T_{ref} to T_{avg} and generates a corresponding error signal (the first of two mentioned previously), which is transmitted to the error summer that initiates control-rod motion according to magnitude and polarity of the error signal. This signal for control-rod motion is developed by the temperature comparator channel.

The second input into the error summer is provided by the power rate comparator channel, which provides a bias for fast response to a change in load as well as to a change in control stability. Turbine first-stage pressure and nuclear power provide the inputs to the power rate comparator channel.

Four nuclear power signals, obtained from the Nuclear Instrumentation System (NIS) power range channels, are auctioneered for the highest average nuclear power. Turbine load (first stage pressure) and the highest average nuclear power are compared by the rate comparator. This unit provides a fast response to power mismatch but also allows the temperature comparator channel to control the reactor during steady-state conditions. This selective control is provided by the derivative action of the rate comparator, which causes the output to "zero" during steady-state conditions, although nuclear power and turbine load signals may not be matched exactly (thus preventing unnecessary oscillation in reactor power level).

The nonlinear gain unit converts the power error signal to a temperature error signal and, in addition, varies the effect of this channel by providing a low gain for small power error and a high gain for large power error (Figure 35-2-4). Increase of the gain for high error inputs increases the initial output of the channel and, therefore, initiates control rod motion more rapidly.

Since changes in reactivity at low power levels have a smaller effect on the rate of change of thermal power than do reactivity changes at high power levels, a variable gain unit is utilized to compensate for this difference. This unit enables the rate comparator channel to provide adequate reactor control at low power levels and stable operation at high power levels. The turbine first-stage pressure channel signal provides turbine load level information to govern the changing of gain in the unit. The response of this unit is shown graphically in Figure 35-2-5.

During load transients, the power rate comparator channel output signal will be added to, or subtracted from, the temperature comparator channel output signal at the error summer to provide a total temperature error signal.

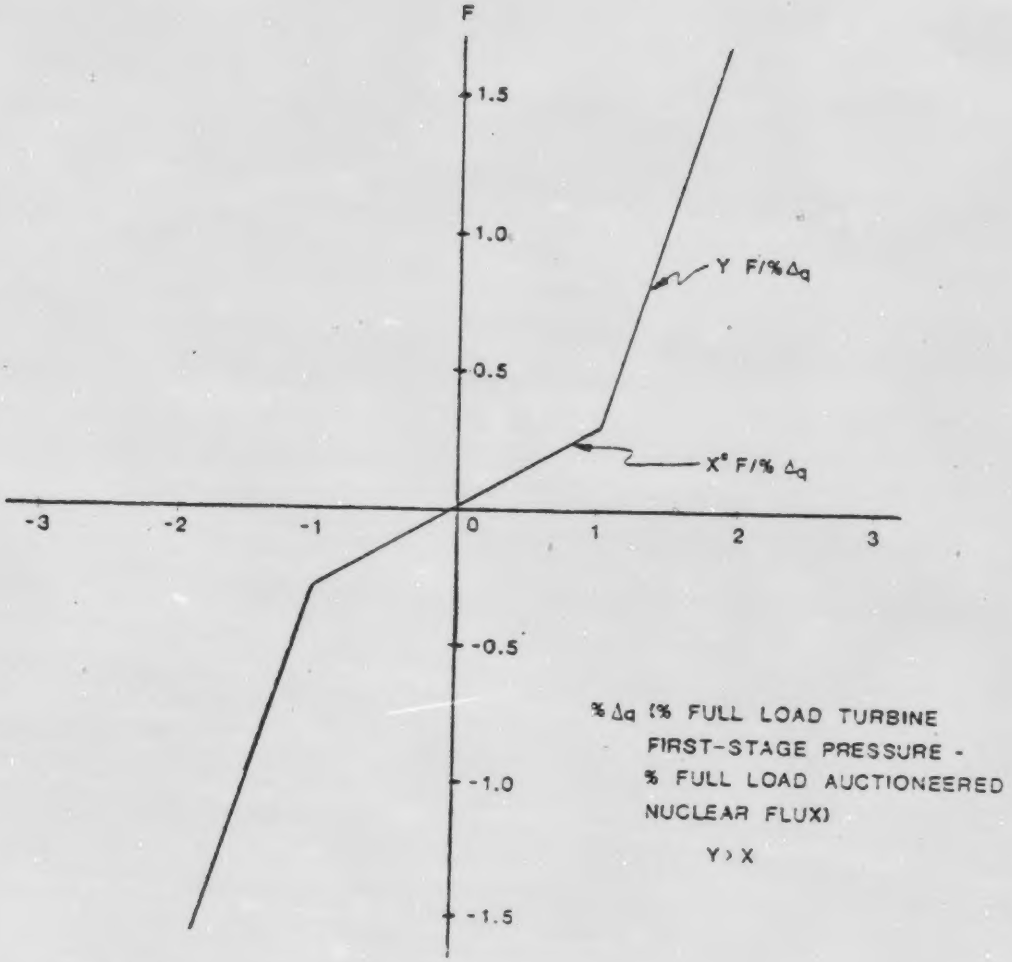


Figure 35-2-4. Power mismatch channel, nonlinear gain.

The temperature error channel signal inputs into the rod-speed controller and the control rod IN/OUT logic unit. The rod-speed controller provides a speed gain, with maximum and minimum speed limits, selected to be consistent with the need for rapid rod motion (Figure 35-2-6) to limit transient overshoot, while at the same time preventing

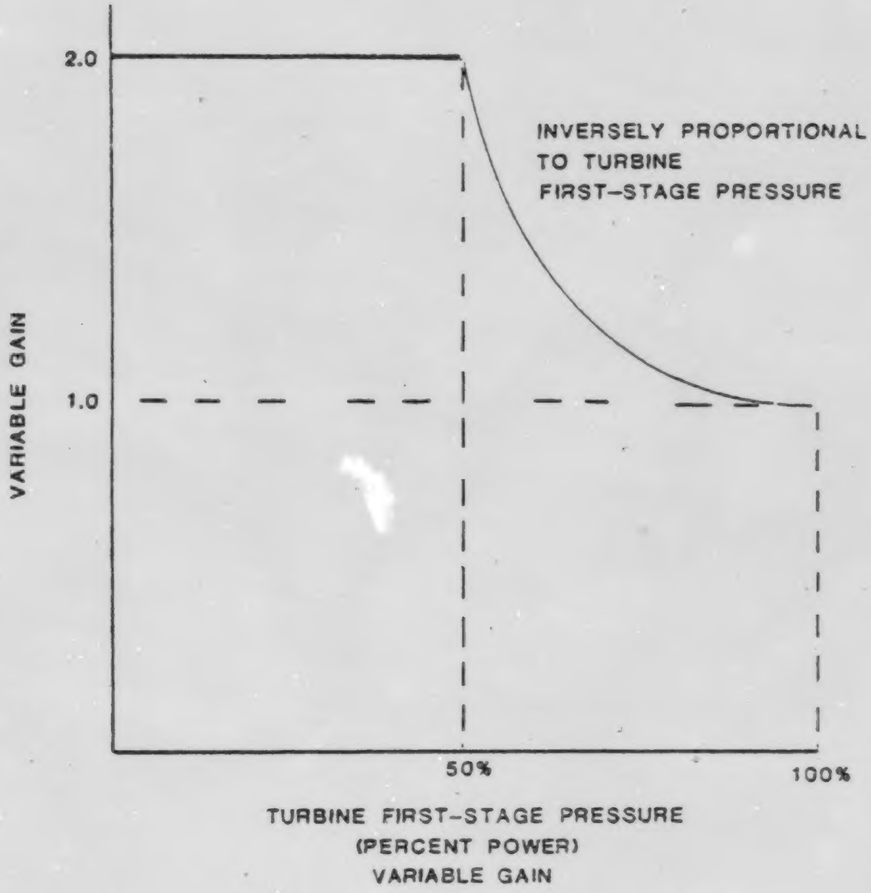


Figure 35-2-5. Turbine first stage pressure (percent power) variable gain.

overcompensation and oscillation. The rod-speed signal generated by the controller is used for automatic operation. The rod IN/OUT logic unit selects the direction of control-rod motion dependent on the polarity of the temperature error signal. The rod-speed controller and the rod IN/OUT logic are provided with speed and direction selectors, respectively, for manual operation.

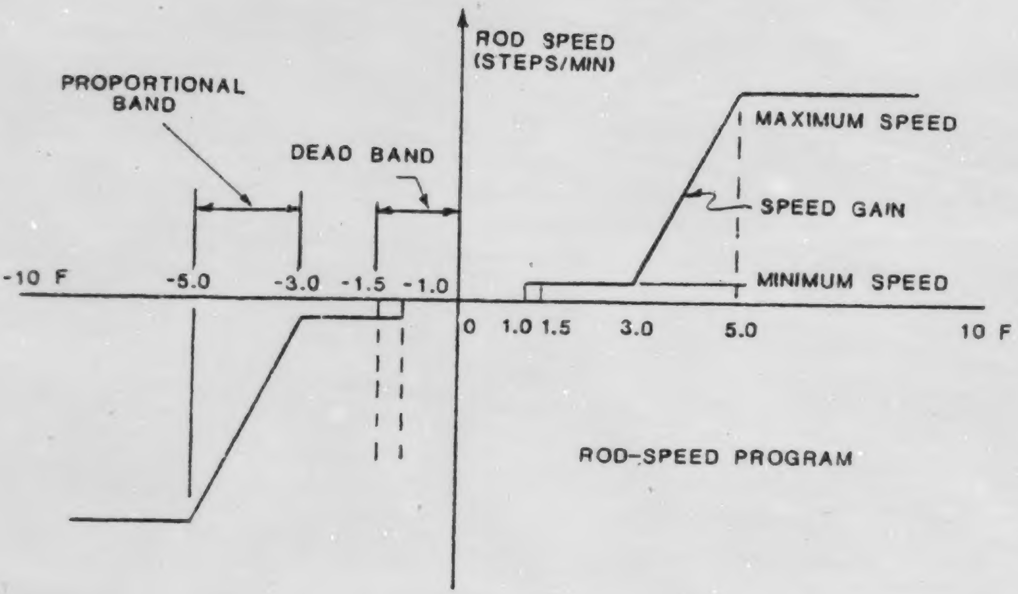


Figure 35-2-6. Rod-speed program.

The rod-speed and direction channels input the respective signals to the rod control system, which consists of the sequencing and limiting logic in conjunction with the power necessary to step the control rods at the desired speed and direction.

STEAM GENERATOR LEVEL

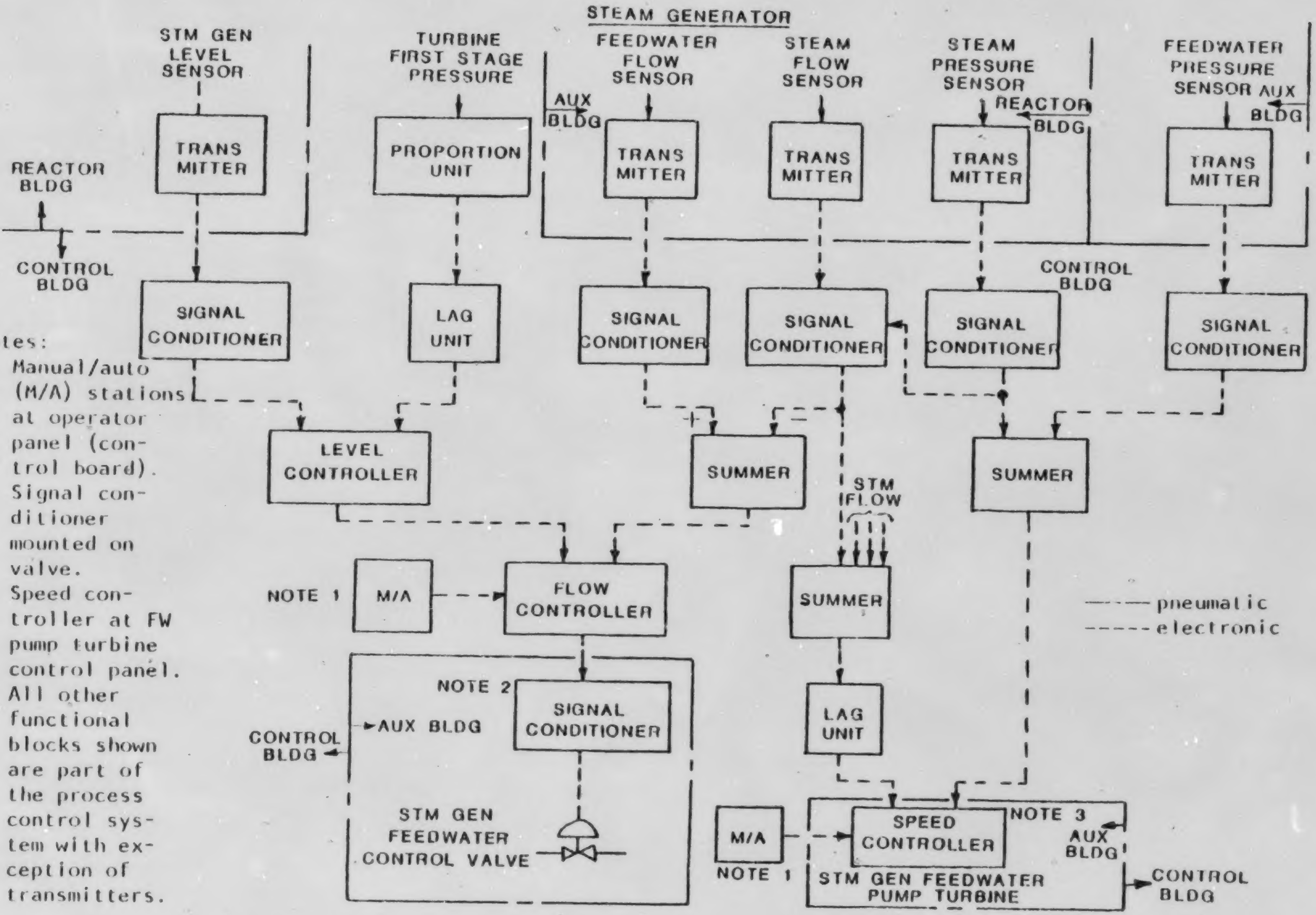
The steam generator level control system consists of a steam generator feedwater flow controller that maintains a programmed water level relative to the turbine load. This programmed level is determined by safety considerations as well as shrink and swell (the change in level due to the change in the average density of the water-steam mixture in the steam generator).

The system also consists of a feedwater pump speed controller that controls pump speed dependent upon steam and feedwater pressure mismatch and totalized mass steam flow in order to maintain adequate pressure across the feedwater control valve.

Figure 35-2-7 is a typical block diagram of a steam generator level control system. Sensors are depicted with associated transmitters and signal conditioners that function in a manner as discussed in the Introduction.

The signal conditioner in the steam generator level channel additionally functions to lag the signal by a certain time period. This level signal then is compared to a programmed level setpoint lagged by the same time period and directly proportional (within limits) to the turbine first-stage pressure. The level and programmed level setpoint are compared at the level controller, which also provides proportional and integral (reset) control adjustments to trim feedwater flow to the steam generator. The controller provides mostly integrating action and little proportional signal. A larger output is provided the longer the level deviates from the setpoint.

The steam flow and pressure and feedwater flow channels are each provided with respective transmitters. The feedwater flow signal is conditioned and provided as an input into the summer. The steam flow signal is conditioned, and pressure is compensated and then compared with the feedwater flow signal at the summer. The output of the summer varies with the difference between steam and feedwater flow signals.


STEAM GENERATOR
STM GEN LEVEL SENSOR
TURBINE FIRST STAGE PRESSURE
FEEDWATER FLOW SENSOR
STEAM FLOW SENSOR
STEAM PRESSURE SENSOR
FEEDWATER PRESSURE SENSOR
AUX BLDG
REACTOR BLDG
AUX BLDG
TRANS MITTER
PROPORTION UNIT
TRANS MITTER
TRANS MITTER
TRANS MITTER
TRANS MITTER
REACTOR BLDG
CONTROL BLDG
CONTROL BLDG
SIGNAL CONDITIONER
LAG UNIT
SIGNAL CONDITIONER
SIGNAL CONDITIONER
SIGNAL CONDITIONER
SIGNAL CONDITIONER
LEVEL CONTROLLER
SUMMER
STM FLOW
SUMMER
NOTE 1
M/A
FLOW CONTROLLER
SUMMER
—— pneumatic
- - - - - electronic
NOTE 2
SIGNAL CONDITIONER
CONTROL BLDG
AUX BLDG
LAG UNIT
STM GEN FEEDWATER CONTROL VALVE
M/A
NOTE 1
SPEED CONTROLLER
NOTE 3
AUX BLDG
STM GEN FEEDWATER PUMP TURBINE
CONTROL BLDG

Notes:
1. Manual/auto (M/A) stations at operator panel (control board).
2. Signal conditioner mounted on valve.
3. Speed controller at FW pump turbine control panel.
4. All other functional blocks shown are part of the process control system with exception of transmitters.

Figure 35-2-7. Steam generator level control system.

The flow controller, which provides for proportional action with little integration, receives the steam-feed, water-flow mismatch signal and corrects for level. The delay in the level controller signal allows the steam-feed, water-flow signal to dominate at the beginning of transients. If the associated manual/auto (M/A) station is in automatic mode, the flow controller (1) generates a control signal that is converted to a pneumatic signal by the signal conditioner (an "electropneumatic converter") and (2) positions the feedwater control valve for the desired flow. In manual operation, the flow controller tracks the manual valve position signal to provide for a bumpless transfer to the automatic mode.

Turbine speed of the steam generator feedwater pump is also controlled in conjunction with the feedwater control valve to maintain adequate pressure across the feedwater control valve.

Steam pressure is compared to feedwater pump discharge pressure to generate a differential pressure signal. The signal is compared to a programmed setpoint, determined from totalized mass steam flow, at the speed controller. The controller then generates a speed-demand signal when in automatic mode.

Steam generator and feedwater pump discharge pressure channels contain respective transmitters and signal conditioners. The summer accepts the output signals from the signal conditioners and generates the differential pressure signal.

The steam generator flow summer sums the flow for each steam generator to generate a total steam flow. The lag unit converts the total steam flow signal to the programmed steam generator — feedwater pump discharge differential pressure. It also filters out short-term steam-flow perturbations in the flow for which a change in programmed differential pressure is not desirable (Figure 35-2-8).

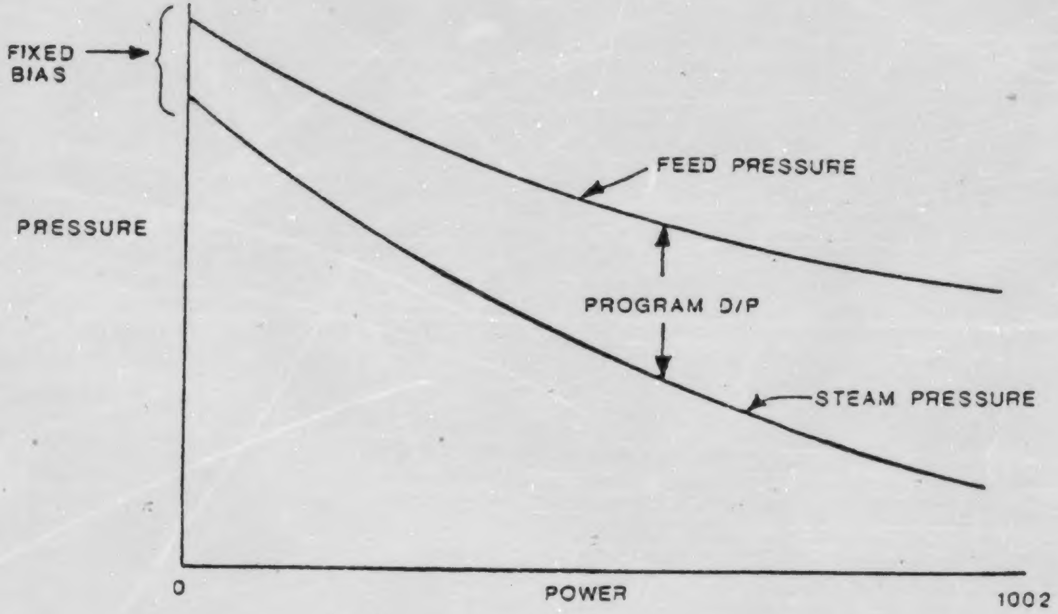


Figure 35-2-8. Program differential pressure.

The speed controller compares the programmed pressure signal with the differential pressure signal to provide the desired control signal in automatic mode. In the manual mode of operation, the controller tracks the manual speed signal for bumpless transfer from manual to automatic mode.

All parameters measured are indicated or recorded at the operator panel (control board) as provided by the respective channel signal conditioners.

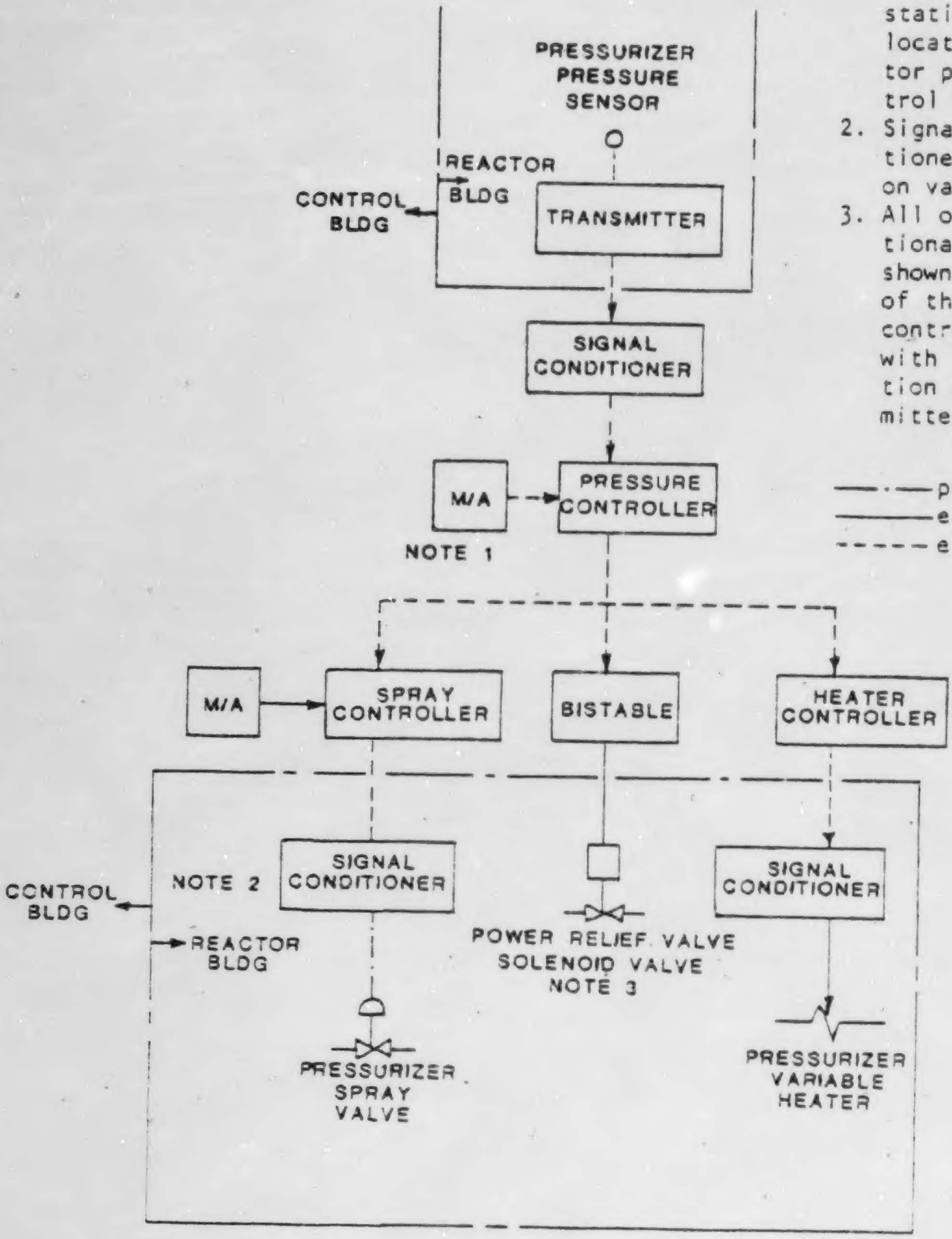
PRESSURIZER PRESSURE

The pressurizer pressure instrumentation and control system serves to maintain operating pressure of the reactor coolant system normal operating parameters of temperature, flow, and power. This control is based upon a pressure control point (P_{ref}) that remains constant under all load conditions.

Pressurizer steam bubble pressure is sensed, converted to an electronic signal, signal conditioned, and provided as an input to the pressure controller (Figure 35-2-9). This pressure, defined and designed as the "reactor coolant pressure," is compared to the pressure reference when in the automatic mode of operation. The deviation from setpoint generated then is supplied to the proportional + integral + derivative portion of the controller. The integral and derivative portions of the controller provide correction factors to the proportional signal for deviations and rate-of-change of deviation, respectively, of the pressure signal.

The error signal thus generated then is used as the controlling signal for the spray valves, power relief valves, and variable heaters.

The spray controller, which has purely proportional characteristics, receives the error signal and outputs a signal with a gain equal to a percentage of valve position opening per pressure deviation (error). This electronic signal then is converted to a proportional pneumatic signal that positions the spray valve accordingly. The spray valve is actuated to reduce pressure when the pressurizer pressure increases to some value above the pressure reference.


PRESSURIZER PRESSURE SENSOR
REACTOR BLDG
CONTROL BLDG
TRANSMITTER
SIGNAL CONDITIONER
M/A
NOTE 1
PRESSURE CONTROLLER
M/A
SPRAY CONTROLLER
BISTABLE
HEATER CONTROLLER
CONTROL BLDG
NOTE 2
REACTOR BLDG
SIGNAL CONDITIONER
POWER RELIEF VALVE SOLENOID VALVE NOTE 3
SIGNAL CONDITIONER
PRESSURIZER SPRAY VALVE
PRESSURIZER VARIABLE HEATER

Notes:

1. Manual/Auto (M/A) stations are located at operator panel (control board).
2. Signal conditioner mounted on valve.
3. All other functional blocks shown are part of the process control system with the exception of transmitter.

—·— pneumatic
——— electrical
----- electronic

Figure 35-2-9. Pressurizer pressure control system.

The pressure bistable will actuate when the pressure-error signal exceeds a predetermined quantity. This actuation, in turn, fully opens the pressurizer power relief to relieve high system pressure caused by a load rejection.

The heater controller, which also has purely proportional characteristics, receives the pressure-error signal and outputs a signal with a gain such that for each psi of deviation (error), the variable heater output changes by a percent of total heat output. The signal then is converted to a proportional current signal that causes the heater(s) to generate the required heat.

Variable heaters are energized to increase pressure when the pressurizer pressure decreases to some value below the pressure reference.

When the pressure controller is in the manual mode of operation, the controller output provides a simulated pressure deivation signal. When the spray controller is in manual mode, the spray valves can be positioned as required without regard to the pressure-error signal.

See Figure 35-2-10 for an illustration of a typical control characteristic curve for pressurizer pressure.

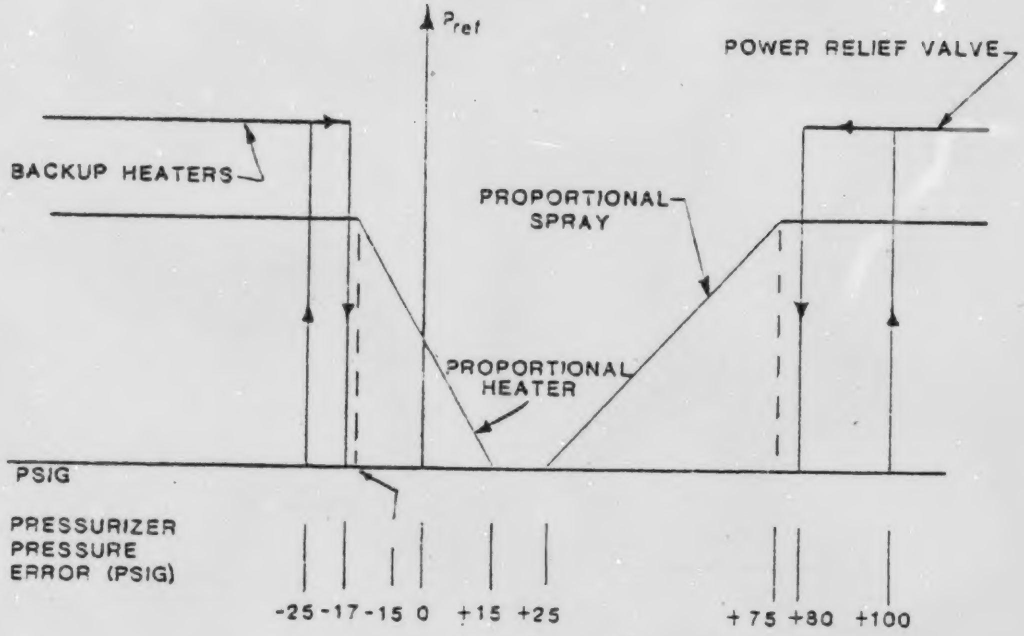
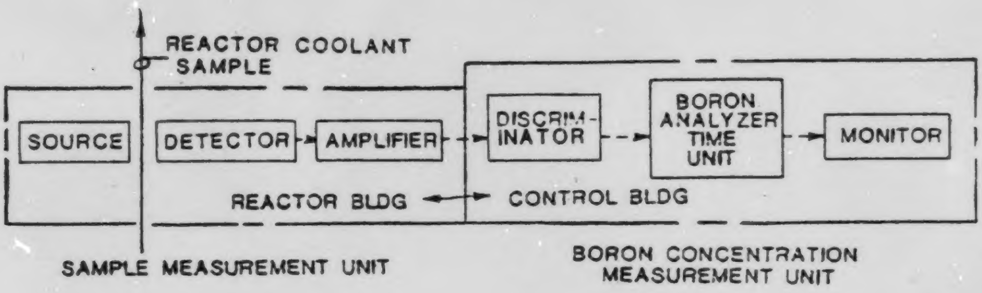

P_{ref}
POWER RELIEF VALVE
BACKUP HEATERS
PROPORTIONAL SPRAY
PROPORTIONAL HEATER
PSIG
PRESSURIZER PRESSURE ERROR (PSIG)
-25
-17
-15
0
+15
+25
+75
+80
+100

Figure 35-2-10. Pressurizer presure control.

BORON MEASUREMENT OF REACTOR COOLANT

Another method of controlling the reactor core reactivity is by varying the boron concentration in the reactor coolant system. Boric acid solution in the coolant provides for regulation of neutron density in the core since the boron-10 isotope has a high capture cross section for neutrons. There are two methods used to measure the boron concentration in the reactor coolant. Laboratory chemical analysis of reactor coolant samples is at present the most common method used. However, electronic means are available for continuous measurement of the reactor coolant boron concentration. This means of measurement is provided by an instrumentation system composed of a sample measurement unit and an electronic console. This system is illustrated in Figure 35-2-11.


REACTOR COOLANT SAMPLE
SOURCE
DETECTOR
AMPLIFIER
DISCRIM-INATOR
BORON ANALYZER TIME UNIT
MONITOR
REACTOR BLDG
CONTROL BLDG
SAMPLE MEASUREMENT UNIT
BORON CONCENTRATION MEASUREMENT UNIT

Notes:
1. Signal conditioners are the amplifier and discriminator shown.
2. Monitor block may consist of digital indication or analog recording.

----- Electronic

Figure 35-2-11. Boron concentration measuring system.

The sample measurement unit contains a neutron source and a neutron detector located in a shielded tank. Piping within the tank maintains reactor coolant sample flow between the neutron source and the detector. Neutron absorption by the boron in the coolant sample flow reduces the number of neutrons that contact the detector per unit time. Therefore, the time required to count a fixed number of neutrons by the detector is variable, depending upon the concentration of the boron solution.

Pulses generated by the neutron detector are amplified to a level that will drive the discriminator. The discriminator allows pulses of sufficient magnitude to be received by the analyzer time unit. The discriminator then discriminates between pulses caused by other ionization energies not produced by neutrons contacting the detector. Inherent or induced electronic noise is also discriminated out.

The boron analyzer time unit receives the pulses and, through electronic pulse counting and time measurement, converts the signal to an analog signal for monitoring by display or recording.

The type of detector used is a BF_3 proportional counter, and the amplifier and discriminator form the detector signal conditioning block (covered elsewhere in this Course). In addition, this system utilizes only one neutron-count channel to perform its function and provides no control other than by human interface through the use of displays.

EXERCISES

1. Sketch the block diagram of an instrument and control system that measures reactor coolant flow and is monitored by indication and computer printout at the operator panel (control board).
2. For the system in Exercise 1, include bistable actuation for alarming at the operator panel and for providing a reactor trip signal to the rod-control system for a reactor coolant low-flow condition.
3. Explain the function, housing, and location of each block or blocks and the signaling used for transmission of the system above.
4. How many channels are involved in the system above?

MATERIALS

None.

PROCEDURES

1. Arrange to visit a power plant (not necessarily a nuclear power plant); and locate the electrohydraulic control system (EHC), both electronic and hydraulic portions, the Turbine-Generator Protection system, and the Excitation system.
2. Identify on a panel sketch all indications on the operator panel that are associated with the turbine-generator instrumentation and control system.
3. Describe the location of as many sensors, illustrated in Figure 35-2-2, as possible.

DATA TABLES

None.

REFERENCE MATERIALS

Considine, D.M., ed. Process Instrumentation and Controls Handbook. 2nd ed. New York: McGraw-Hill Book Company, 1974.

Harrer, J.M. and Beckerley, J.G. Nuclear Power Reactor Instrumentation Systems Handbook. Vol. 1. Springfield, VA: U.S. Atomic Energy Commission Office of Information, Technical Information Center, 1973.

Weedy, B.M. Electric Power Systems. 2nd ed. New York: John Wiley & Sons, 1972.

1. Define the following terms:
   a. EHC.

   b. Signal conditioner.

   c. PMG.

   d. T_{avg}.

   e. T_{ref}.

   f. RTD.

   g. NIS.

   h. M/A.

   i. D/P.

2. Sketch and label a block diagram for the instrumentation and control system for four of the five systems listed:
   a. Main turbine generator.

   b. Reactor control.

   c. Steam generator level.

   d. Pressurizer pressure.

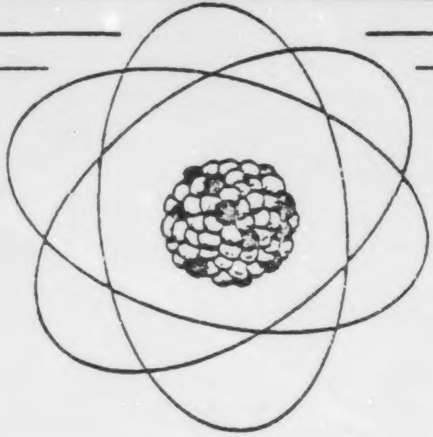
e. Boron measurement of reactor coolant.

3. For the four systems chosen above, describe the function of each block and the type of signal conversion and transmission used.

4. Identify each different channel (or loop) of each system chosen above.

5. Discuss where each block would be typically located in a nuclear power plant.

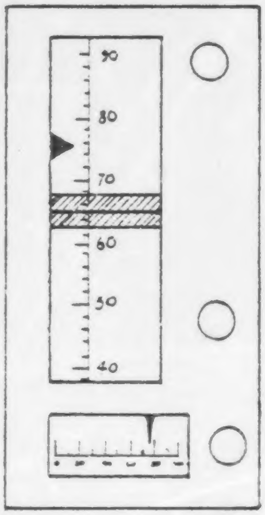
6. Identify which equipment houses each of the blocks.

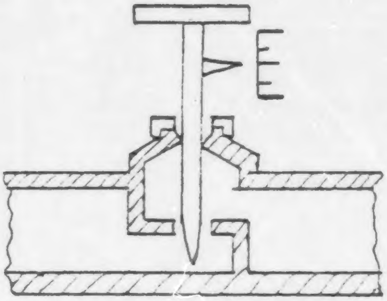


NUCLEAR TECHNOLOGY

MODULE 35-3

RECORDING AND DISPLAY DEVICES





SYSTEMS AND COMPONENTS

COURSE 35

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

CONTENTS

COURSE 35 SYSTEMS AND COMPONENTS

MODULE 35-1 Electrical Distribution

MODULE 35-2 Instrumentation and Control for Major Plant Components

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MODULE 35-4 Process Control Loops and Devices

MODULE 35-5 Cathode-Ray Tube Systems (CRT)

MODULE 35-6 Preventive Maintenance for Systems and Components

MODULE 35-7 Instrument Reliability

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INTRODUCTION

The operation of a fossil-fuel power plant, as well as of a nuclear plant, requires that personnel monitor, observe, and record all plant parameters on a continuous basis. These requirements increase greatly in a nuclear power plant because of the number of different parameters that are required in its safe operation. Display and recording devices assist operators and technicians in maintaining the plant in a safe condition at all times. Such devices supply visual indications of the plant processes. In this module, the many types of recording and display devices, together with the advantages and disadvantages of each, are discussed.

MODULE PREREQUISITES

The student should have completed Course 3, "Principles of Process Instrumentation"; Course 5, "Introduction to Nuclear Systems"; and Course 6, "Instrumentation and Control of Reactors and Plant Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List and describe the two types of continuous recording devices used in instrumentation circuits.

2. Describe advantages and disadvantages of the two types described in Objective 1.
3. Discuss use of these types in control circuits.
4. Describe the three types of recorders used in instrumentation circuits; list their relative advantages and disadvantages.
5. Describe the five different types of display devices and how each is utilized in the circuit control.
6. Explain how graphics are used in display devices.
7. Describe the use of display devices in sequential monitoring.
8. Name and define five indicating devices commonly found in nuclear power plants.

In a nuclear power plant, there are two basic devices by which plant information is recorded for the operator's use during all phases of plant operation. These devices – the recorder and the computer – aid plant personnel in the monitoring and in the controlling of plant operations.

The Nuclear Regulatory Commission requires that all paperwork dealing with the operation of nuclear power plants be kept on file for five years. Strip-chart recorders use roll paper; and in five years, paper storage would require a large space. With a round-chart recorder, the amount of space used would not be as great, but still would be large.

ELECTRONIC, PNEUMATIC, AND MECHANICAL RECORDERS

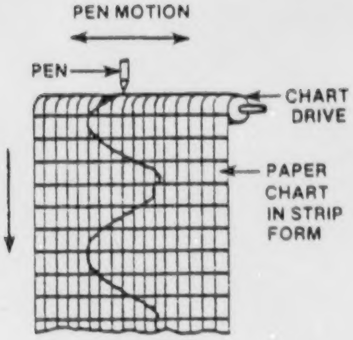
The three basic types of recorders are (1) the electronic recorder, which is the most common type; (2) the pneumatic recorder; and (3) the mechanical recorder. Both the electronic and pneumatic types are available in the strip-chart and round-chart configurations. The mechanical type is available only in the round-chart design.

STRIP-CHART AND ROUND-CHART RECORDERS

The Strip-Chart Units

Figure 35-3-1 is a simplified drawing that illustrates the basic operation of a strip-chart recorder.

Figure 35-3-1. Basic arrangement of the strip-chart recorder.



The position of the pen is determined by the voltage or pneumatic pressure being recorded. As the paper strip moves, a record of the amplitude variation as a function of time is produced on the paper in the form of the inked line made by the pen.

The recorder depicted in Figure 35-3-1 is the single-pen type; however, many of the recorders in nuclear plants contain multiple channels and pens, as discussed later in this module, under the heading of "Multi-channel Recorders."

Recorders are used in nuclear power plants, as well as in other industrial fields, because of their ability to show an operator the process-variable trends over a period of time. The value of this information depends upon recorder chart speed, which is controlled by a motor. The motor is connected either to the take-up reel or to the drive wheel, which pulls paper under the pen system. The take-up reel is connected in such a way that its clutch allows the paper to wind up but not to rip the paper. The circular chart has the same speed options, but its chart is limited to seven or eight days in capacity.

Some recorders are not used by an operator but, because of their design, are used by technicians in the monitoring of process variables or in the troubleshooting of control systems. These recorders are designed with higher accuracy and more versatility than those on control boards.

One disadvantage of the strip-chart recorder is the take-up mechanism for the chart paper. Problems here can prevent the recorder from operating properly by not allowing the paper to move freely. Another disadvantage involves the inking system. Some inks do not dry quickly enough, which causes the pen to tear through the chart paper as it moves over it. New recorders are equipped with flair-tip pens that have proved to be quite successful.

The Round-Chart Unit

The round-chart recorder (Figure 35-3-2) records data on a round paper disc. Because of today's miniaturization of power-plant instrumentation and control boards, this type of recorder is not used in control rooms; however, for remote application and field use, it still has practical value.

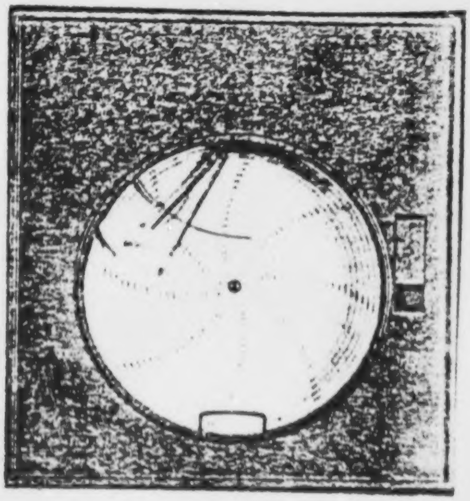


Figure 35-3-2. A round-chart recorder.

THE ELECTRONIC STRIP-CHART RECORDER

In the electronic recorder (Figures 35-3-3 and 35-3-4), an input of a given voltage or current coming from the field (process variable) is used to drive the recorder to its proper value. Electronics in the recorder determine where the pointer will line up by applying the input signal to a servo amplifier that drives a servomotor and feedback potentiometer. The servomotor will continue to drive the pen-carriage mechanism until feedback voltage is equal to input voltage. At this point, the recorder is balanced at the process variable input and will stay at this level until the process changes and again causes the servo amplifier or balancing motor to become unbalanced.

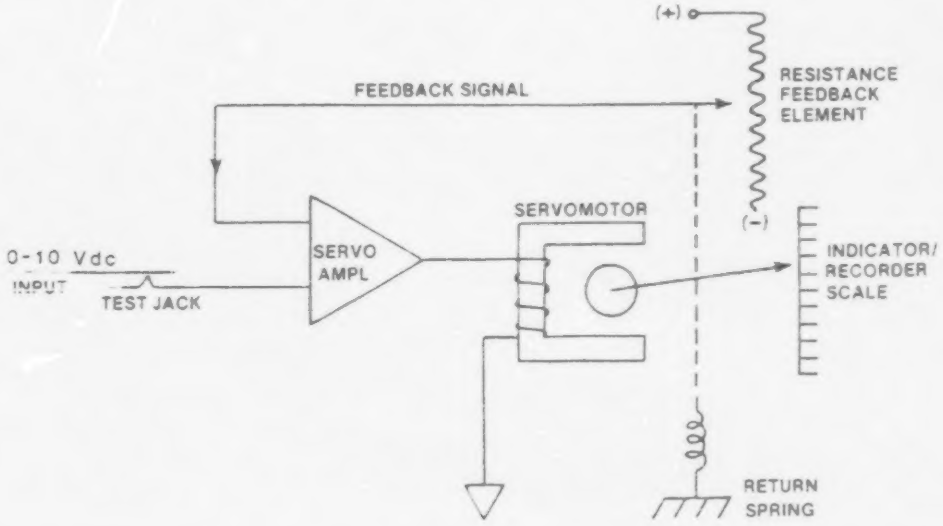

(+)
FEEDBACK SIGNAL
RESISTANCE FEEDBACK ELEMENT
(−)
SERVOMOTOR
0-10 Vdc
INPUT
TEST JACK
SERVO AMPL
INDICATOR/ RECORDER SCALE
RETURN SPRING

Figure 35-3-3. Schematic of electronic strip-chart recorder.

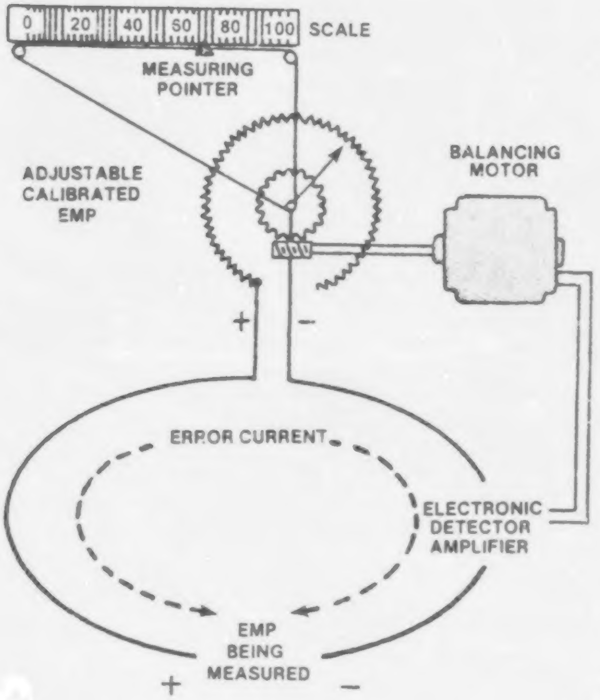

0
20
40
60
80
100
SCALE
MEASURING POINTER
ADJUSTABLE CALIBRATED EMP
BALANCING MOTOR
+
−
ERROR CURRENT
ELECTRONIC DETECTOR AMPLIFIER
EMP BEING MEASURED
+
−

Figure 35-3-4. Typical mechanism of electronic strip-chart recorder.

Electronic recorders, as well as the other recorder types, must be calibrated according to the instruction manual for each model. Step-by-step instructions for the calibration of electronic recorders are presented in the Procedures section of this module.

THE PNEUMATIC RECORDER

In the pneumatic recorder (Figure 35-3-5), air of a specific pressure (at 3-15, 6-30, or 3-27 psi) is used for operation. This pressurized air is piped to a sealed assembly (the aluminum can in Figure 35-3-5) inside the

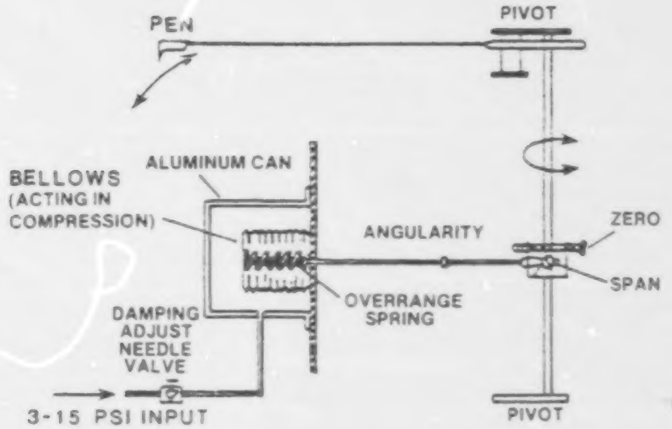

PEN
PIVOT
ALUMINUM CAN
BELLOWS (ACTING IN COMPRESSION)
ANGULARITY
ZERO
SPAN
OVERRANGE SPRING
DAMPING ADJUST NEEDLE VALVE
3-15 PSI INPUT
PIVOT

Figure 35-3-5. Typical mechanism of a pneumatic recorder.

recorder. Inside the assembly, this air pressure acts upon a compressible bellows mechanically connected to the pen-drive mechanism. With an increase in air pressure, the bellows compresses, causing the linkage to rotate the pointer in an increasing direction. As input pressure decreases, the bellows expands and pulls the linkage, causing the pointer to move in a decreasing direction.

THE MECHANICAL RECORDER

The mechanical recorder is mounted to a diaphragm assembly (Figure 35-3-6). The diaphragm is connected directly to the process variable by sensing lines.

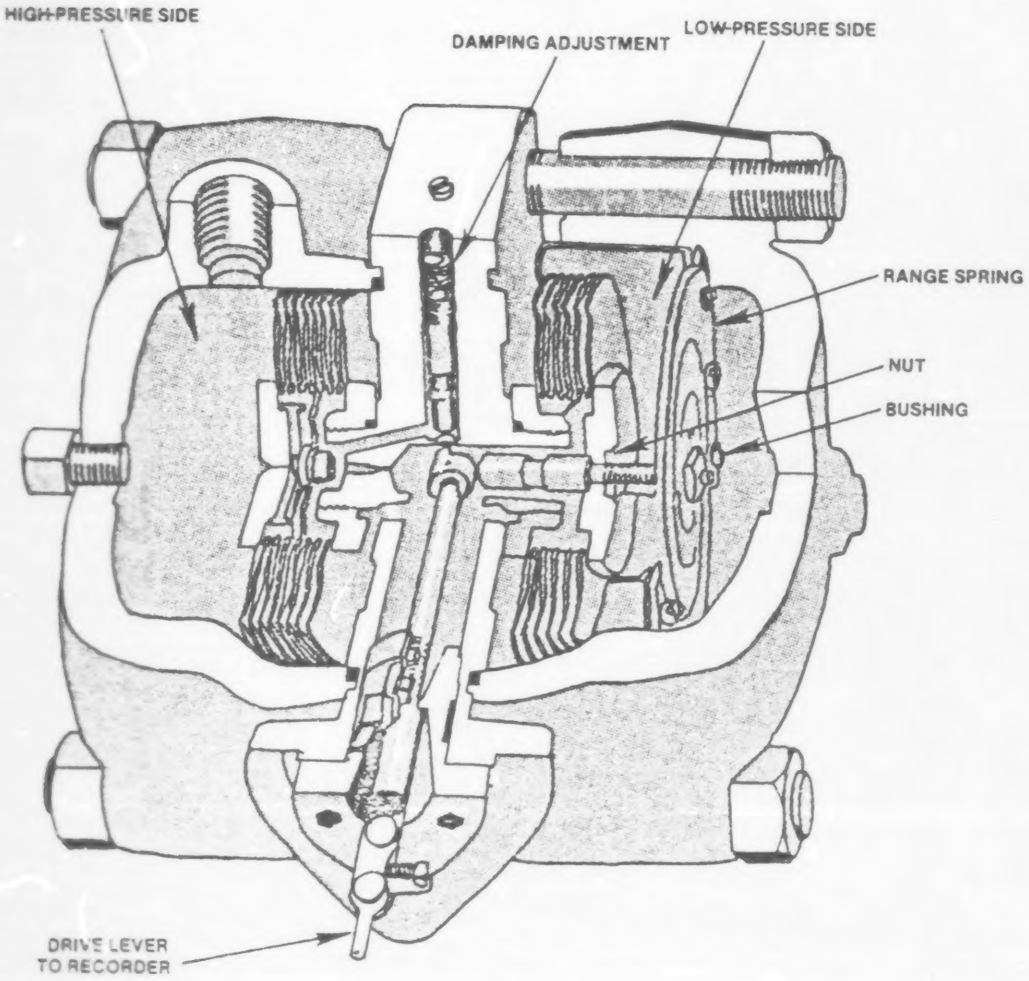

HIGH-PRESSURE SIDE
DAMPING ADJUSTMENT
LOW-PRESSURE SIDE
RANGE SPRING
NUT
BUSHING
DRIVE LEVER
TO RECORDER

Figure 35-3-6. Diaphragm assembly of a mechanical recorder.

In such a flow recorder, when no pressure is applied, the diaphragm experiences equal pressure on both sides. As the process increases, this pressure will begin to increase, causing the diaphragm to move in one direction. This movement deflects the mechanical linkage, causing the pen mechanism to move in the upscale direction. If the process decreases, the opposite pen motion occurs.

Mechanical recorders are used only in the field and at, or near, the process variable.

MULTI-PEN RECORDERS

Pneumatic and mechanical recorders are designed for use with the pen-carriage inking system. Electronic recorders contain either the pen-carriage type or the pad-wheel type. On a pen-carriage recorder, there can be from one to four pens; on the pad-wheel type, up to 24 different points. Only one process parameter is being monitored and recorded by the single-point recorder. In plant recorders, if from one to four parameters are being monitored, the recorder usually is the pen type. This type of recorder is easy to read because its input is constant; however, when there are four pens on a recorder, it is more difficult to calibrate, repair, and keep clean.

With a four-pen recorder, the number of electronics and drive motors has multiplied by four. The sizes of one-pen and four-pen recorders are identical, and space and ease of calibration become less with each additional pen. Each added pen also increases calibration and maintenance difficulty.

If a plant had only four-pen recorders, a great amount of control-board space could be required for them. With the advent of multipoint recorders, this problem was solved. In the multipoint system, inputs to the recorder always are present. Inputs are switched by relays in one model; when these relays are energized, they connect the inputs to the recorder measuring circuit. The relays are energized by a gear-driven relay switch connected to the print mechanism. This arrangement allows input and print wheels to monitor the same point and to be in synchronism at all times.

In another type of recorder, inputs are selected by the use of a selector switch connected to a motor that operates the switch one step at a time. The print wheel is connected to the same motor, which keeps all points lined up. The principal advantage of a multi-point recorder is the increased number of points that can be monitored by one recorder; for example, the temperature of each main turbine bearing. All bearing temperatures can be monitored on one recorder, and each temperature can be compared against the temperature of other bearings. Another example is the monitoring of data from thermocouples inside the reactor head. The operator can monitor coolant flow temperatures throughout the core, and can compare them to each other to determine if a hot spot has developed in the fuel area. The multipoint recorder, because of the extra amount of electronics, requires a greater amount of time for maintenance or for troubleshooting. Calibration, however, is the same as for the single-point recorder.

The digital recorder is of great value when there is a large number of inputs (more than 30). Inputs are switched by relays, step switches, or electronic devices, depending upon manufacture. The recorder has a digital display that looks at each input and a fast-speed strip-chart recorder that will operate if any input exceeds a predetermined setpoint. Inputs are divided into groups or banks that will be based upon their location in relation to each other. The recorder can be programmed to operate the strip chart either for one input in the bank or for the complete bank of inputs. Switching of inputs is done at a remote location, with the recorder mounted in the control area. As with any digital device, the indication is only what the actual input is, as compared to the total span; therefore, a knowledge is required of the complete span parameters before the information is useful.

RECORDERS IN CONTROL CIRCUITS

Use of recorders in control circuits of nuclear power plants is, by and large, just for indication; however, recorders can provide alarm indication, by use of a switch on the pen carriage. When the pen reaches a predetermined setpoint on its scale, an alarm is annunciated. The function performed by the switch also can be accomplished with electronics, if a bias or trip setting of opposite polarity is set into a comparator circuit and if the process input is connected to the comparator. When input becomes greater than the bias, an alarm condition results. Recorders function primarily as indicators to an operator or a technician of some plant process. The control aspect of recorders is very limited.

COMPUTERS

The other type of recording device is the computer, which takes input voltage, current, or resistance and converts it into a computer language. It then places the information on magnetic tapes or magnetic discs for storage and later use. When this information is needed, the computer retrieves it and converts it into a language that a printer or terminal will understand.

Computers can play either a very active role or merely a supportive role in power plant operations. In the Power Utility industry, most computers play a supportive role and are used mainly for data acquisition of plant parameters. The industry, at present, does not believe that computers can control an operating power plant as well as a person can. Even those plants that have the capacity to use a computer plant control seldom employ it. One of the main reasons for not using a computer for control is the computer's availability record, or the computer's up time versus its down time. The computer's only other use, then, is its ability to record and to display plant parameters.

A computer has the capacity to store or to record great amounts of information in a relatively small area; it can process and store this information with great speed and accuracy. With disc packs and magnetic tapes, a computer can store and retrieve information rapidly for the operator's immediate use, or for use at a later time.

One disadvantage of computers is the amount of equipment needed for recording and displaying. A computer uses a language of its own, and all display devices must have the ability to "talk" to the computer; therefore, there is a great amount of interfacing equipment between peripheral equipment and computer. Technicians will do most of their work on this extra equipment. Also, computers give only a digital output indication; whereas, recorders are analog-reading devices, which are a greater help to an operator because the whole span of the process is visible. A computer shows only what the process is reading at that time — the complete range of the process is not shown.

Another aid to the technician or operator is the trend recorder. This recorder is tied to the computer; and by operator selection, the process variable can be displayed on the recorder. For the reading to have meaning, an operator must understand the span of the process variable involved.

The computer typewriter is discussed later in this module, under the headings "THE COMPUTER TYPEWRITER AS AN INDICATOR" and "GRAPHICS."

INDICATORS

With the use of recorders, there is a permanent record of the process parameters of a plant while in operation. There is also a need to monitor plant operations with equipment that will give a visual indication to the operator of changes that are occurring in the process at all times. This equipment can be mounted remotely or on the control board in the control room.

THE BOURDON PRESSURE GAGE

Pressure gages are the most common of all remote indicators in a power plant. The pressure gage is mounted on the process or isolated from the process by a diaphragm. In the in-line method, the pressure gage is mounted on a pipe that has direct contact with the process. A pressure gage contains a tube called a "Bourdon tube," which is connected by mechanical linkage to a pointer (Figure 35-3-7). As pressure increases, the Bourdon tube expands in an outward direction, causing the linkage to move in an increasing direction and causing the point to move upscale.

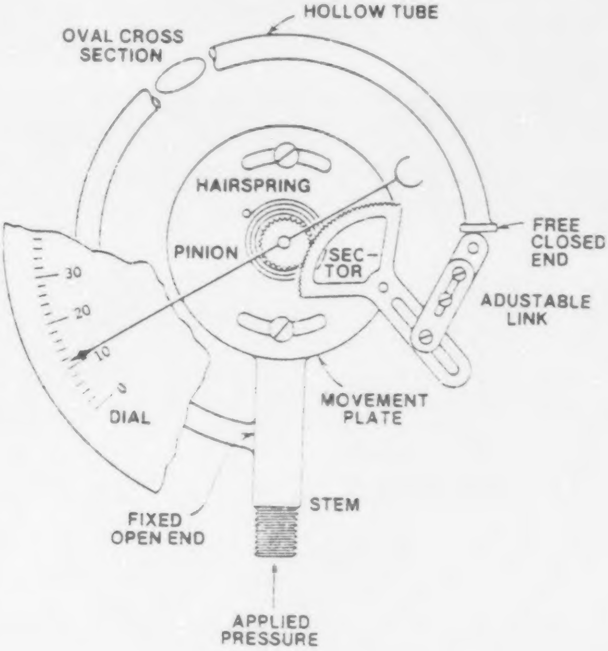

HOLLOW TUBE
OVAL CROSS SECTION
HAIRSPRING
PINION
SEC-TOR
FREE CLOSED END
ADUSTABLE LINK
30
20
10
0
DIAL
MOVEMENT PLATE
STEM
FIXED OPEN END
APPLIED PRESSURE

Figure 35-3-7. The Bourdon pressure gage.

THE DIAPHRAGM-OPERATED PRESSURE GAGE

The diaphragm-operated pressure gage functions in much the same way as the Bourdon gage. The diaphragm separates process fluid from the gage. These types of gages are utilized in plant systems when the process is corrosive or harmful to either the gage or to plant personnel.

THE EDGEWISE INDICATOR

Another type of indicator used in power plants is the edgewise indicator, mounted on the control board for the operator's use. It receives a voltage or current input and is calibrated to the span of the instrument, usually a transmitter that sends the indicator its signal. The indicator contains a movable pointer that indicates on a scale whatever the process is that it is measuring; for example, flow, pressure, or temperature. Depending upon manufacture, the indicators have a permanent-magnet moving coil, with a suspension system of either pivots, jewels, and control springs, or metallic bands attached to tension springs that prevent the pointer from sagging.

Edgewise indicators play a supportive role in control. They give the operator a constant knowledge of what the plant parameters are doing; by observing these indicators, the operator will know either when a parameter has changed or when one must be changed manually.

THE DIGITAL INDICATOR

The digital, panel-mounted indicator gives a reading from an output of a transmitting thermocouple, RTD, etc. Input is applied to the digital indicator and compared with an input signal through the signal input switch and the input capacitor to the integrator amplifier. Output of the integrator, at this time, is of the same polarity as the input signal. This polarity is sensed by the zero-crossing detector and causes a reference switch of opposite polarity to close, effecting a discharge of the integrating capacitor to a zero level, at which time the zero-crossing detector turns off the oscillator and leaves the counters set to a BCD number that represents the input signal. The BCD number is decoded into a seven-segment form and actuates current-source drivers that light up the segments of a seven-bar, gas-discharge display tube.

The digital indicator is utilized for indication only, but gives the operator more data with which to control the plant.

The gage is used for indication only and is mounted at, or near, the actual process. Its only purpose in a control system is to allow the operator or technician to observe what is happening to the process at any given moment. As with most instrumentation, there are some exceptions to this statement. There are indicators that have internal switches that allow either an alarm or a trip condition to occur. Micro switches mounted to the indicator movement allow this type of action to be accomplished. These instruments, called "indicating switches," measure pressure, temperature, or flow.

THE COMPUTER TYPEWRITER AS AN INDICATOR

The computer typewriter is like any other typewriter, except that it contains the electronics required to receive a message from the computer. The computer typewriter is in the control room, where the operator can observe it at all times.

The computer typewriter is employed for indication as well as for storage of information about the plant's operation. The typewriter allows the operator to look at as many parameters in the plant operation as necessary, as long as they are tied to the computer. This procedure causes the operator to be more versatile in plant control by giving the operator ability to monitor any parameter that might be giving problems, or to monitor a parameter continuously if it relates to the safe operation of the power plant. The typewriter also is used to print out hourly logs for operation of the plant. From some of these logs, the operational efficiency of the power plant can be determined. Other logs can be used for personnel monitoring of radiation received during a month. Another log might identify an individual who has entered a limited-access area and how long the person was there. Depending upon the computer and its application, the logs printed by the typewriter can be for almost anything important to a plant's operation.

GRAPHICS

Use of graphics in modern-day control-board applications is becoming more and more frequent. By using a computer to detail and display process diagrams, the operator has the advantage of being able to see the complete system, or any part of it. Diagrams are displayed on a cathode-ray tube (CRT) used in conjunction with the computer. There is a problem with this system, however, in that much programming and instrumentation are required for its operation.

Sequential Monitoring

In sequential monitoring, data is gathered in the time frame in which each event occurs. The computer monitors points to be used in the sequence-of-events printout. The computer will see an interrupt by one of the contacts and stop what it is doing to log the time it occurs. Every time the computer sees an interrupt, it will record the time. After a given period, it will print out on a typewriter all information it has stored, in the sequence in which the interrupts occurred in relation to time.

USE OF RECORDING AND DISPLAY DEVICES ILLUSTRATED

The use of recording and display devices can be illustrated by the following discussion of the steam generator level control.

The reactor coolant system (RCS) supplies heat needed to convert the feedwater to steam and to remove heat from the RCS (Figures 35-3-8 and 35-3-9). The reactor coolant, which circulates through metal tubes, heats the feedwater within the steam generator to produce steam. The feedring steam generator illustrated in Figure 35-3-8 releases drops of water from a ring that encircles the generator.

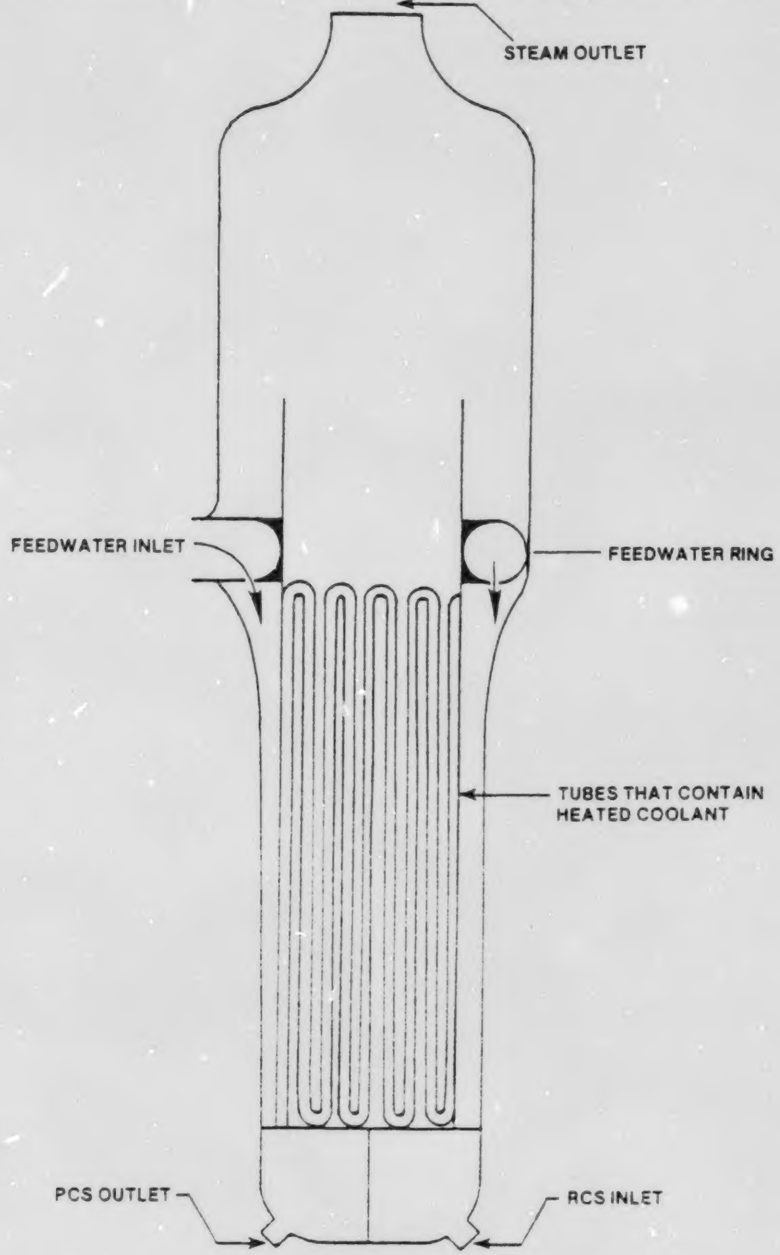

STEAM OUTLET
FEEDWATER INLET
FEEDWATER RING
TUBES THAT CONTAIN HEATED COOLANT
PCS OUTLET
RCS INLET

Figure 35-3-8. Feedring steam generator.

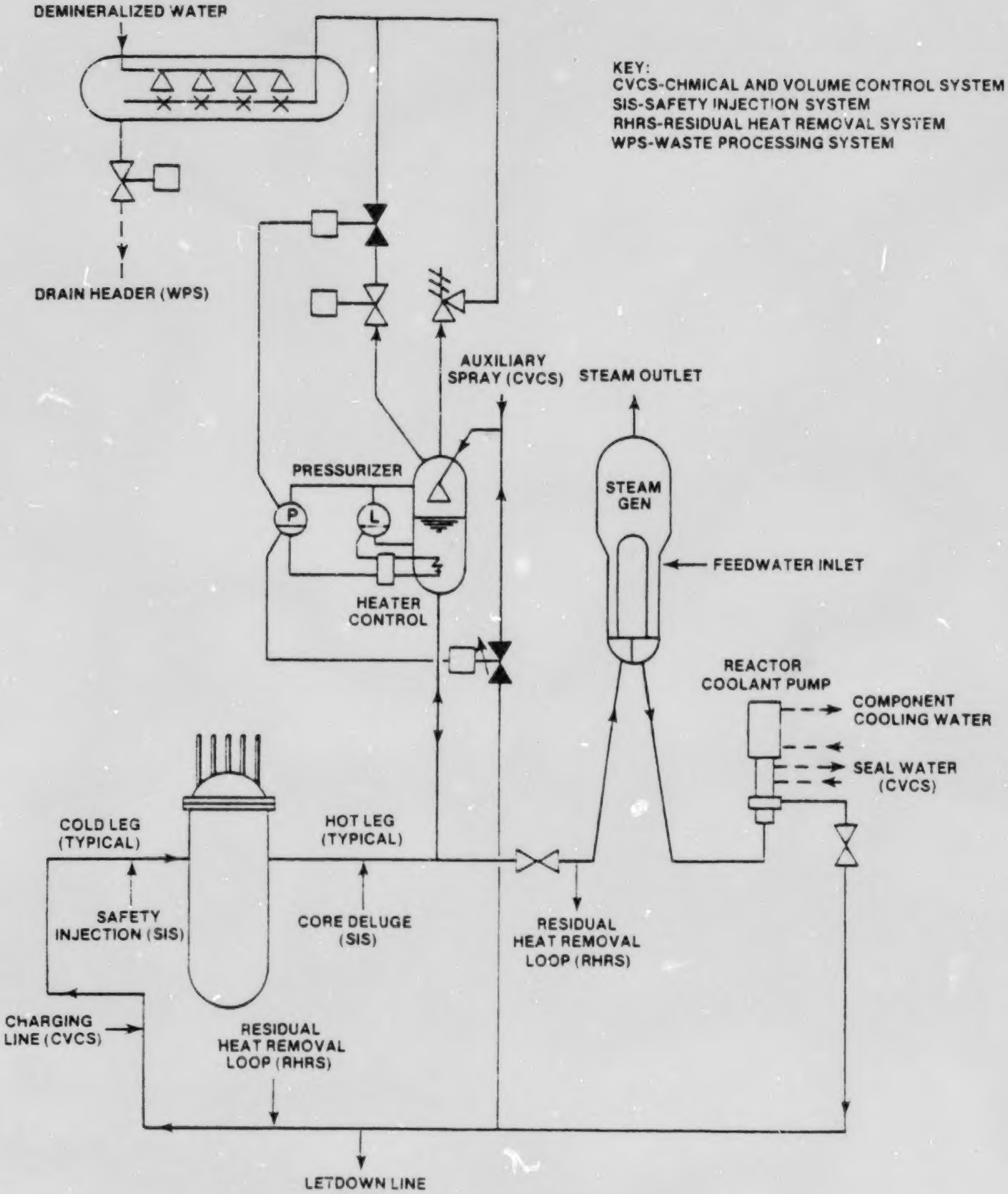

DEMINERALIZED WATER
KEY:
CVCS-CHMICAL AND VOLUME CONTROL SYSTEM
SIS-SAFETY INJECTION SYSTEM
RHRS-RESIDUAL HEAT REMOVAL SYSTEM
WPS-WASTE PROCESSING SYSTEM
DRAIN HEADER (WPS)
AUXILIARY SPRAY (CVCS)
STEAM OUTLET
PRESSURIZER
P
L
STEAM GEN
FEEDWATER INLET
HEATER CONTROL
REACTOR COOLANT PUMP
COMPONENT COOLING WATER
SEAL WATER (CVCS)
COLD LEG (TYPICAL)
HOT LEG (TYPICAL)
SAFETY INJECTION (SIS)
CORE DELUGE (SIS)
RESIDUAL HEAT REMOVAL LOOP (RHRS)
CHARGING LINE (CVCS)
RESIDUAL HEAT REMOVAL LOOP (RHRS)
LETDOWN LINE (CVCS)

Figure 35-3-9. Reactor coolant system, flow diagram.

Steam generator level must be kept at a high enough value to prevent the RCS from overheating due to lack of heat transfer. In the control system, the level signal is sent to many indicating and recording devices (Figure 35-3-10).

The instruments are isolated from the protection system to prevent inadvertent trips of the reactor. Control system indicators supply the operator with all information needed to operate the plant at a safe condition.

Depending upon control system and outputs, the indicators and recorders can be of many types. Some of the more common types are Westinghouse Model 252 Indicator, L & N Speedomax H Recorders, and Westinghouse 2500 Computer. Contractor and AE and supplier of equipment determine the indicators and recorders to be used. Most are identical and have the same operating functions.

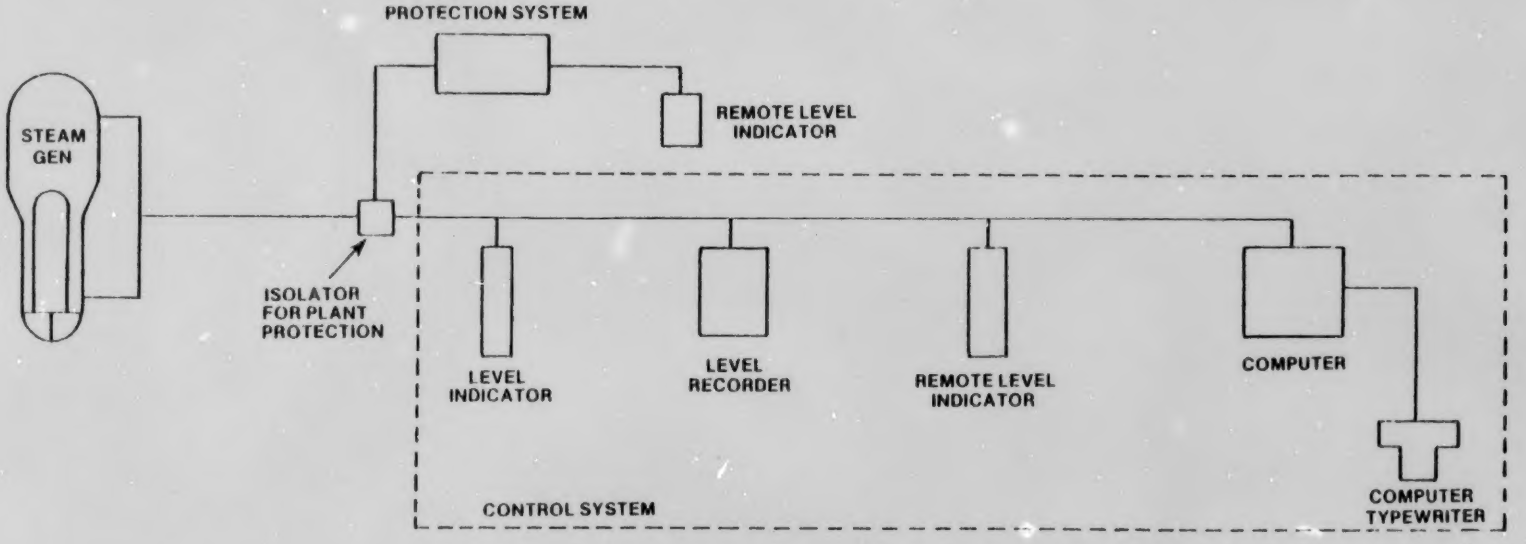

PROTECTION SYSTEM
REMOTE LEVEL INDICATOR
STEAM GEN
ISOLATOR FOR PLANT PROTECTION
LEVEL INDICATOR
LEVEL RECORDER
REMOTE LEVEL INDICATOR
COMPUTER
COMPUTER TYPEWRITER
CONTROL SYSTEM

Figure 35-3-10. Control system indicating and recording devices.

EXERCISES

1. What is one reason for using a recorder instead of a digital indicator?
2. List disadvantages of the computer for power plant indications.
3. List advantages of using a computer rather than a recorder.

MATERIALS

Leeds and Northrup two-pen recorder or equivalent.

Power supply, 0-30 volts d.c., Hewlett-Packard 6215A or equivalent.

Hydraulic tester, Ametek 3-TA.

Two pressure gages, Ashcroft 1082-S, 0-100 psi. (One must be in proper calibration already; the other is to be calibrated against the first.)

PROCEDURES

RECORDER CALIBRATION

NOTE: In this experiment, a power supply is utilized to simulate a transmitter. If the input to the recorder is in amps, follow Steps 1 through 6; if in milliamps, follow Steps 7 and 8. The correct input is determined by the range of the recorder used. If the recoder is a dual- or multi-channel unit, each channel must be calibrated separately.

1. Connect output of power supply to input of recorder, and connect a DVM to same input. (Refer to Figure 35-3-11.)

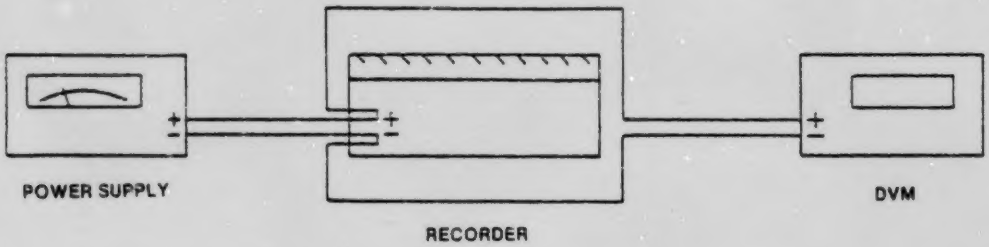


Figure 35-3-11. Laboratory calibration setup for recorder.

2. Set up power supply output to minimum recorder input.
3. Adjust "ZERO" on amplifier until recorder indicator reads zero.
4. Set power supply output to maximum recorder input, and adjust "SPAN" on amplifier card for full-scale reading on recorder indicator.
5. Repeat Steps 2 - 4 until there is no change at either end of the recorder scale. (The reason for the repetition is this: The ZERO and SPAN adjustments react to each other.)
6. If the recorder is equipped with a "GAIN ADJUSTMENT," set gain to a point at which response is fast yet not so fast that it will overshoot the input of the power supply.

7. If input to recorder is in milliamps, connect DVM in series with power supply, as in Figure 35-3-12.

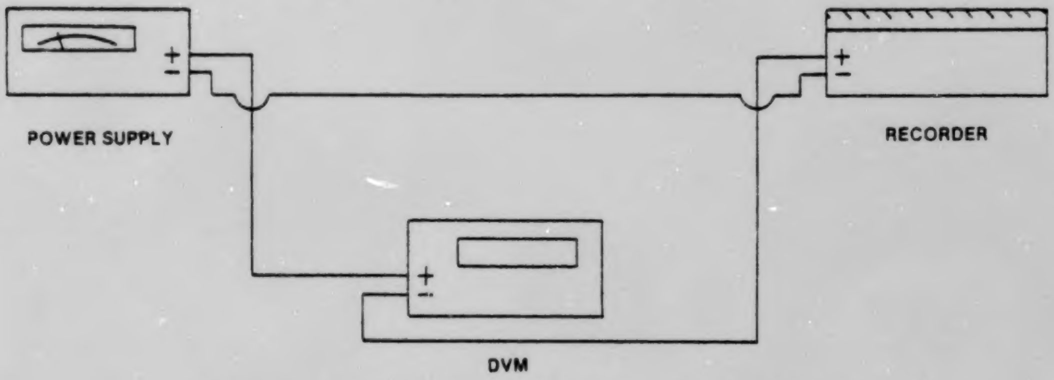


Figure 35-3-12. Recorder calibration when input is in milliamps.

8. Repeat Steps 2 through 6.

GAGE CALIBRATION

NOTE: Use of the Ametek 3-TA hydraulic tester aids the technician in the calibration of gages and other instruments such as pressure switches and some transmitters. The technician also can utilize the tester to determine pressure in instrument sensing lines.

The Ashcroft 1082-S pressure gages used in this experiment are common in nuclear plants. Each of these gages contains a bronze Bourdon tube that deflects under internal pressure and moves an indicator hand to which it is attached.

1. Connect gage to be tested to one side of tester, and connect a calibrated gage (or one of known accuracy) to the other side, as illustrated in Figure 35-3-13.

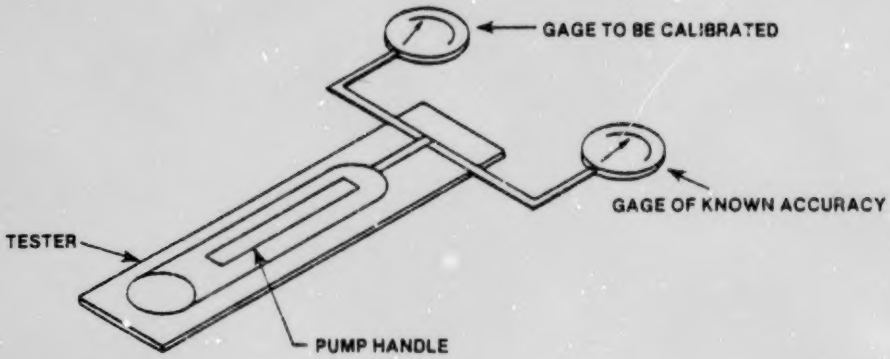
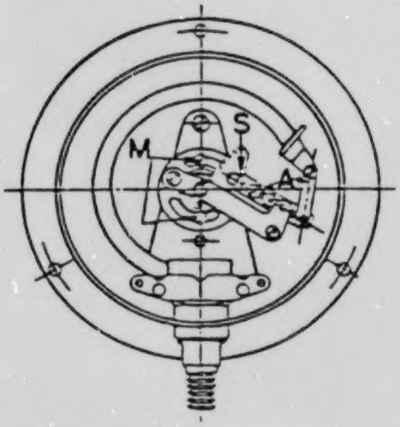


Figure 35-3-13. Gage calibration with hydraulic tester.

2. With tester pump handle, pump both gages until the calibrated gage indicates its maximum reading.
3. If the gage to be calibrated does not indicate the same pressure as the calibrated one, calibrate it as outlined in Steps 4 through 9.
4. Refer to gage illustrated in Figure 35-3-14.
5. Reset gage hand or adjust the micrometer pointer to agree with reading of calibrated gage.
6. If the simple adjustments in Step 5 do not restore desired accuracy when gage is tested at various pressures, the cause for the continued misadjustment must be determined. The gage may exhibit sluggish action, or the pointer may travel too swiftly or too slowly.



SYMBOLS:

S- SLIDE

A- ANGLE OF PULL

M- ADJUSTING SCREWS

Figure 35-3-14. Gage adjustment points.

7. If the gage is sluggish in response, clean all bearings and gear teeth. Adjust hairspring to eliminate all backlash. (Too much spring tension causes friction and drag.)
8. The slide "S" moved in or out changes the ratio of motion. A Bourdon tube may change slightly so that its motion under a given internal pressure is either more or less; therefore, the slide "S" is moved to compensate or agree with the Bourdon tube's motion. When the pointer moves too fast, the slide "S" should be pushed out; if the pointer moves too slowly, the slide should be pushed in. When properly set, tighten slide screws.
9. Even with the slide at the best location, it is necessary to have the angle of pull "A" just right, else the pointer will travel too fast at either the low or high end of the scale. Loosen screws "M", and rotate the whole movement to give the desired angle "A." If angle "A" is acute, the pointer will travel fast on the first part of the scale and slower on the last part. For

example, a gage may read perfectly from zero to the top of the dial, or one-half of the scale, and from there on go gradually slower. In this case, increase the angle "A" a little at a time until the hand begins to go faster for the last half of the scale. "A" = 76° approximately. When a new movement is being adjusted to an old gage, this rotary feature is extremely convenient.

DATA TABLE

None.

REFERENCE MATERIALS

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Weedy, B.M. Electric Power Systems. 2nd ed. New York: John Wiley & Sons, 1972.

TEST

1. List and describe the two types of continuous recording devices used in instrumentation circuits.

2. Describe advantages and disadvantages of the two types of devices described in Test item 1.

3. How are these two types of devices used in control circuits?

4. Describe the three types of recorders utilized in instrumentation circuits, and list their relative advantages and disadvantages.

5. Explain the function of at least four display devices in the control circuit.

6. How are graphics employed in display devices?

7. What is "sequential monitoring"? How is it accomplished with display devices?

8. Briefly explain the functions of the following indicators:
   a. The Bourdon pressure gage.

   b. The diaphragm-operated pressure gage.

   c. The edgewise indicator.

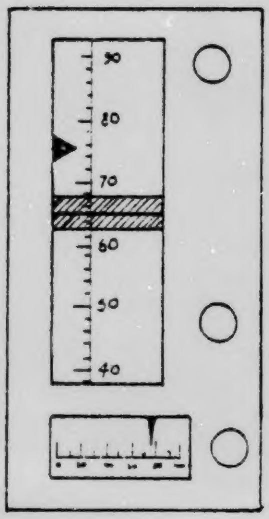
   d. The digital indicator.

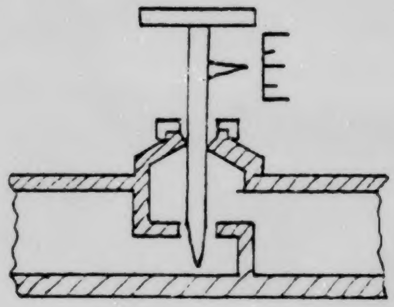
   e. The computer typewriter as an indicator.

NUCLEAR TECHNOLOGY

MODULE 35-4

PROCESS CONTROL LOOPS & DEVICES





SYSTEMS AND COMPONENTS

COURSE 35

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

CONTENTS

COURSE 35 SYSTEMS AND COMPONENTS

MODULE 35-1 Electrical Distribution

MODULE 35-2 Instrumentation and Control for Major Plant Components

MODULE 35-3 Recording and Display Devices

⇨ MODULE 35-4 Process Control Loops and Devices

MODULE 35-5 Cathode-Ray Tube Systems (CRT)

MODULE 35-6 Preventive Maintenance for Systems and Components

MODULE 35-7 Instrument Reliability

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INTRODUCTION

The functional blocks of each system described in Module 32-2, "Instrumentation and Control for Major Power Plant Components," consist of one or more discrete components (hereafter referred to as "modules"), which together provide the functional characteristics of each block.

The present module explains (1) the function of each discrete component (module) of each functional block, (2) the dynamic behavior of the associated loop, and (3) the objective of the reactor and pressurizer pressure instrumentation and control systems of a typical pressurized water reactor.

The student will need a copy of Module 35-2 for reference to its illustrations.

MODULE PREREQUISITES

The student should have completed Course 3, "Principles of Process Instrumentation"; Course 6, "Instrumentation and Control of Reactors and Plant Systems"; Course 33, "Control Systems I"; Course 34, "Control Systems II"; and the previous modules of this Course. (Module 35-2, "Instrumentation and Control of Major Power Plant Components," is an indispensable prerequisite because reference is made to many illustrations therein.)

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Explain the objective of each control system.
2. Draw the instrumentation and control loop diagram (closed loop) for the following:
   - Reactor control system.
   - Pressurizer pressure control system.
3. Describe the function of each module of each functional block in each loop.
4. Discuss the dynamic behavior of each loop.

REACTOR CONTROL SYSTEM

The objective of the reactor control system is to maintain a programmed average temperature of the reactor coolant by selective positioning of the control rods in the automatic mode of operation. Any manual control of the control rods bypasses this control system (Figure 35-4-1, which is identical to Figure 35-2-3 in Module 35-2). The system has the additional objective of initially compensating for changes in core reactivity caused by xenon transients and/or fuel depletion. Further compensation is provided by adjustments in the concentration of reactor coolant boron.

The reactor control system in the functional block diagram in Figure 35-4-1 consists of three input parameters — T_{avg}, main turbine first-stage pressure, and reactor power.

T_{avg} is provided by four channels, which are auctioneered high. As indicated by Figure 35-4-1, the auctioneered T_{avg} channel consists of two major functional blocks. These blocks consist of the module illustrated in Figure 35-4-2. The first signal conditioner converts the resistance as provided by the RTD to a proportional voltage signal. Conversion is accomplished by the resistance-to-voltage (R/E) converters — TY-1A (hot leg) and TY-1B (cold leg). Each signal is equivalent to a temperature in the range between 530°F and 630°F and input into the summer TY-1C to obtain T_{avg}; that is, $T_{avg} = (T_H + T_C)/2$. Each T_{avg} provided by the four channels is auctioneered high by TY-5A. This method of auctioneering provides proper control for safe operation of the reactor if one channel were to fail high. A failed-low channel would have no effect. Output of the auctioneer provides the auctioneered T_{avg} (T'_{avg}) parameter with a range of 530°F to 630°F. T'_{avg} is further conditioned by the second

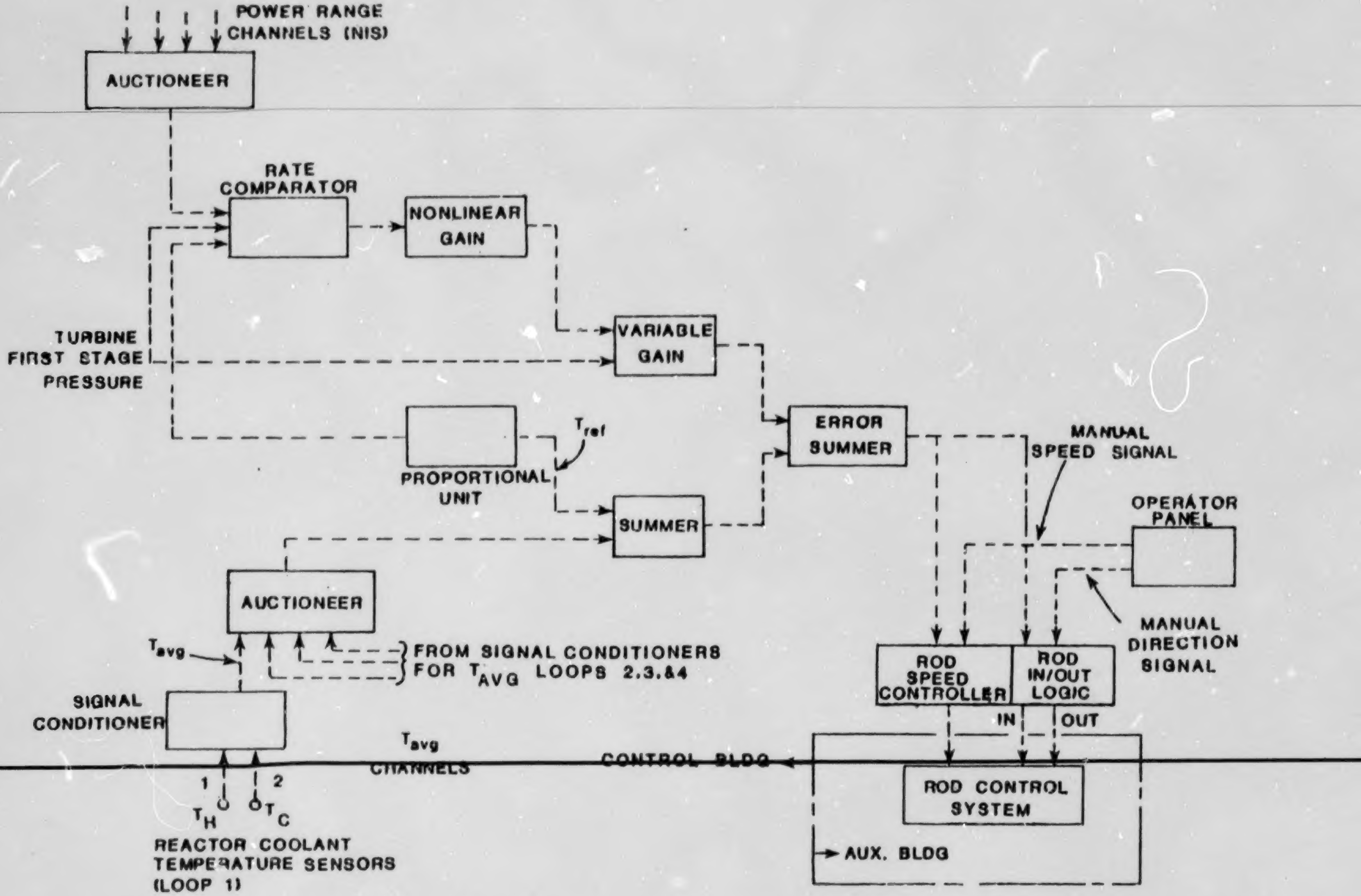

POWER RANGE CHANNELS (NIS)
AUCTIONEER
RATE COMPARATOR
NONLINEAR GAIN
TURBINE FIRST STAGE PRESSURE
VARIABLE GAIN
PROPORTIONAL UNIT
T ref
ERROR SUMMER
SUMMER
MANUAL SPEED SIGNAL
OPERATOR PANEL
AUCTIONEER
MANUAL DIRECTION SIGNAL
T avg
FROM SIGNAL CONDITIONERS FOR T AVG LOOPS 2,3,&4
ROD SPEED CONTROLLER
ROD IN/OUT LOGIC
SIGNAL CONDITIONER
IN
OUT
T avg CHANNELS
CONTROL BLDG
ROD CONTROL SYSTEM
1
2
T H
T C
REACTOR COOLANT TEMPERATURE SENSORS (LOOP 1)
AUX. BLDG

Figure 35-4-1. Reactor control system.

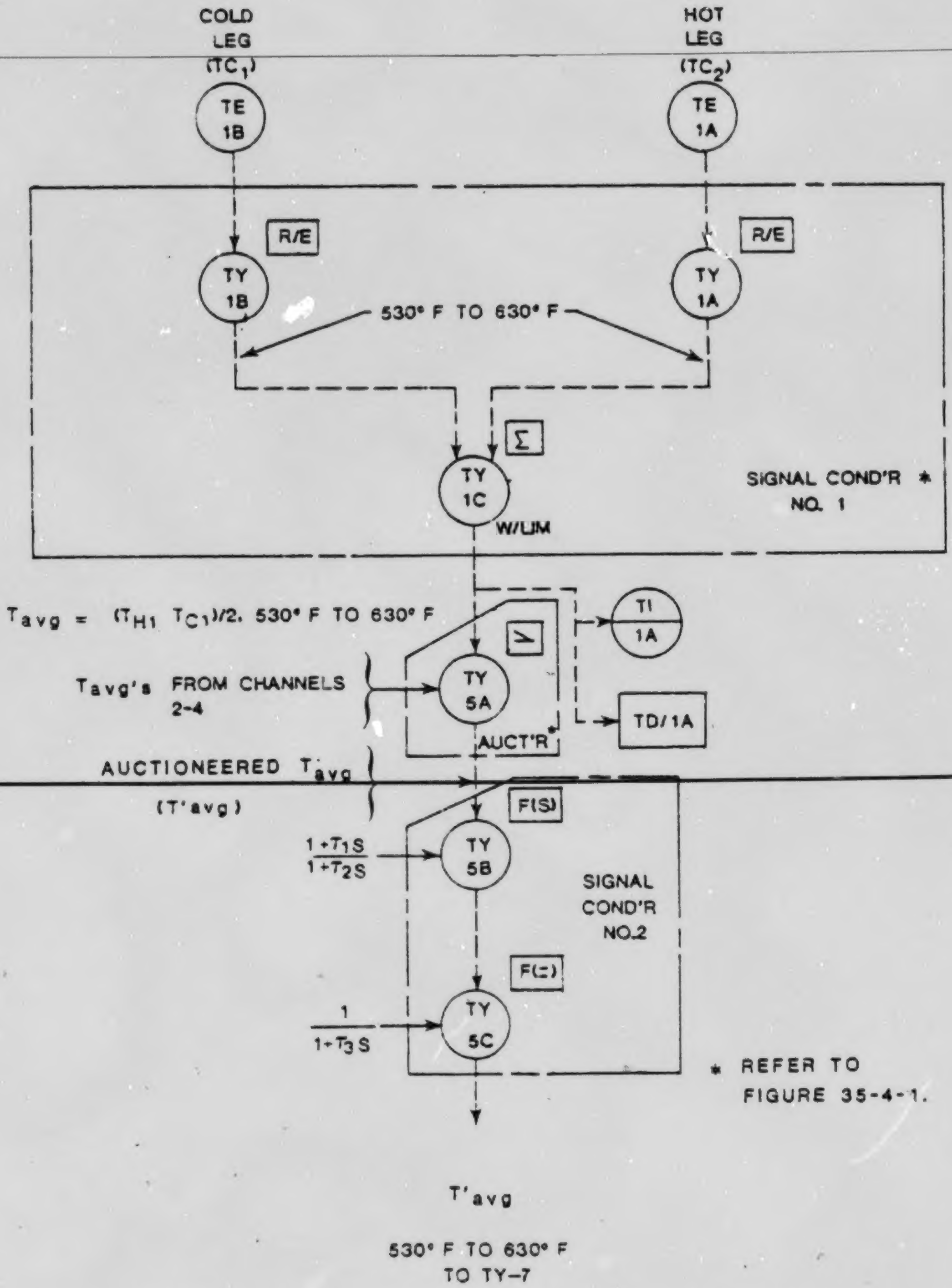

COLD LEG (TC1)
HOT LEG (TC2)
TE 1B
TE 1A
R/E
R/E
TY 1B
TY 1A
530° F TO 630° F
Σ
TY 1C
W/LIM
SIGNAL COND'R * NO. 1
Tavg = (TH1 TC1)/2. 530° F TO 630° F
TI 1A
>
Tavg's FROM CHANNELS 2-4
TY 5A
TD/1A
AUCT'R*
AUCTIONEERED Tavg (T'avg)
F(S)
1+T1S / 1+T2S
TY 5B
SIGNAL COND'R NO.2
F(=)
1 / 1+T3S
TY 5C
* REFER TO FIGURE 35-4-1.
T'avg
530° F TO 630° F TO TY-7

Figure 35-4-2. Auctioneered T_{avg} channel.

signal conditioner (not illustrated in Figure 35-4-1), consisting of the module TY-5B and TY-5C. TY-5B provides a fast response to a sudden change in T'_{avg} by producing a large output for a short period and then slowly decaying to the nominal T'_{avg}. This signal then is filtered by TY-5C, which has a faster time constant than TY-5B. TY-5C lags the output of TY-5B for control stability, but ensures a quick response, as well. TY-5B and TY-5C are lead/lag (L/L) modules, with TY-5B having the L/L function and TY-5C having the lag function. The transfer function of each is indicated in Figure 35-4-2; and they are $\frac{1 + \tau_1 s}{1 + \tau_2 s}$ and $\frac{1}{1 + \tau_3 s}$, respectively, where τ is the lead-time constant and τ_2 and τ_3 are the lag-time constants. The output of TY-5C provides the conditioned T'_{avg} input into the summer TY-7 in Figure 35-4-3.

At the output of the summer TY-1C, T_{avg} is displayed by the indicator TI-1A at the operator's panel and also is provided as an input into a plant computer by the input buffer TD/1A. This indication and computer input also are provided by the other three T_{avg} channels.

The second input parameter referred to previously is the main turbine first-stage pressure, which is signal conditioned before providing an input into the reactor control system. This conditioning was functionally shown in Figure 35-2-2 and is illustrated in discrete modules in Figure 35-4-4.

The loop power supply, PQY-1, functions as a signal conditioner, as well. First-stage pressure sensed and converted to an electronic signal by the pressure transmitter PT-1 is conditioned by PQY-1. This module outputs the pressure signal to an indicator at the operator's panel (PI-1) and computer buffer (PD/1) and is lagged (filtered) by a

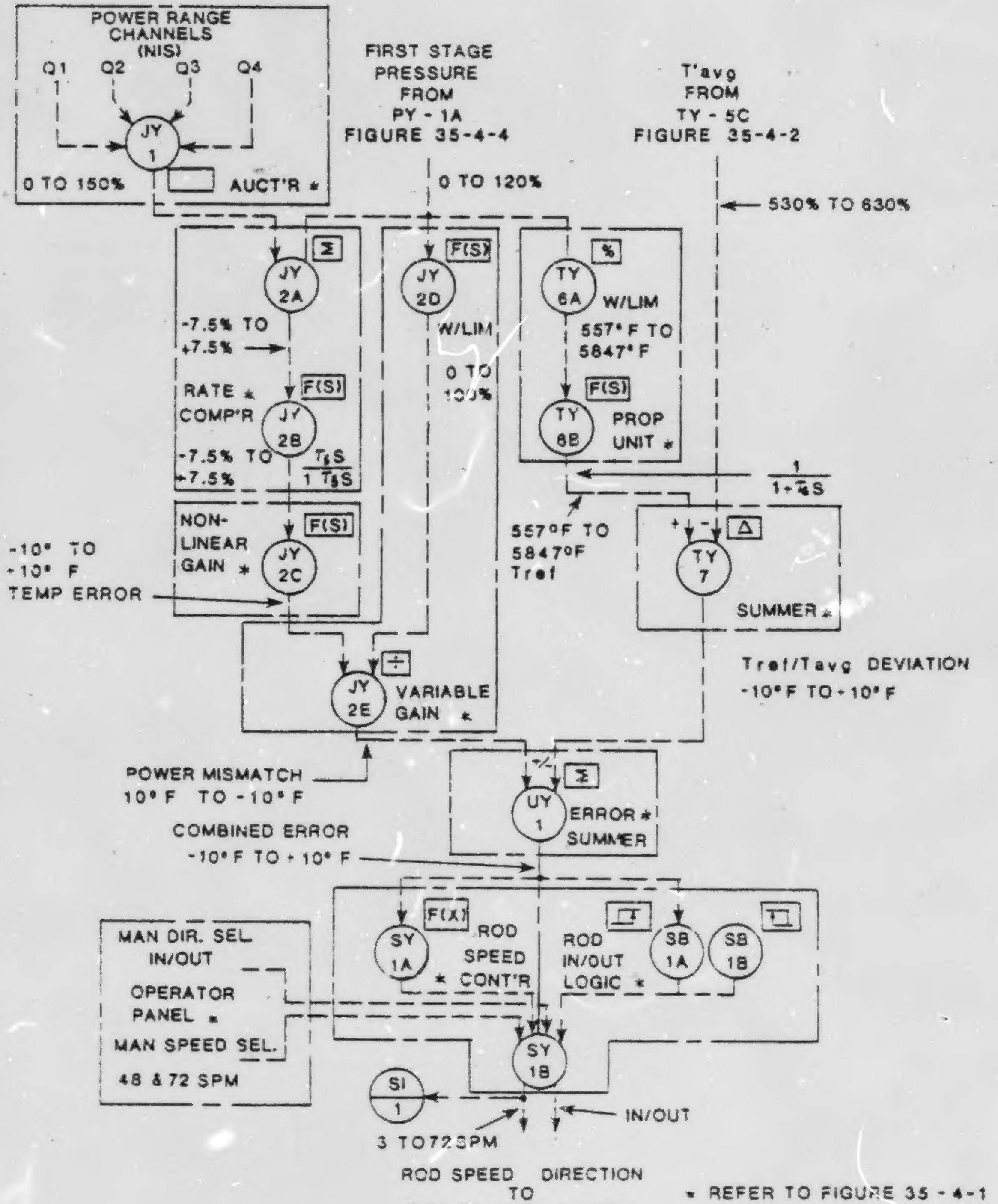

POWER RANGE CHANNELS (NIS)
Q1
Q2
Q3
Q4
JY 1
0 TO 150%
AUCT'R *
FIRST STAGE PRESSURE FROM PY - 1A FIGURE 35-4-4
T'avg FROM TY - 5C FIGURE 35-4-2
0 TO 120%
530% TO 630%
Σ
JY 2A
-7.5% TO +7.5%
F(S)
RATE * COMP'R
JY 2B
-7.5% TO +7.5%
$\frac{T_{s}S}{1\ T_{s}S}$
F(S)
JY 2D
W/LIM
0 TO 100%
%
TY 6A
W/LIM
557° F TO 5847° F
F(S)
TY 6B
PROP UNIT *
$\frac{1}{1+T_{s}S}$
NON-LINEAR GAIN *
F(S)
JY 2C
-10° TO +10° F TEMP ERROR
557°F TO 5847°F Tref
+
-
Δ
TY 7
SUMMER *
÷
JY 2E
VARIABLE GAIN *
Tref/Tavg DEVIATION -10° F TO +10° F
POWER MISMATCH 10° F TO -10° F
+/-
Σ
UY 1
ERROR * SUMMER
COMBINED ERROR -10° F TO +10° F
F(X)
SY 1A
ROD SPEED * CONT'R
ROD IN/OUT LOGIC *
SB 1A
SB 1B
MAN DIR. SEL. IN/OUT
OPERATOR PANEL *
MAN SPEED SEL.
48 & 72 SPM
SY 1B
SI 1
IN/OUT
3 TO 72 SPM
ROD SPEED DIRECTION TO ROD CONTROL SYSTEM
* REFER TO FIGURE 35 - 4-1

Figure 35-4-3. Reactor control system.

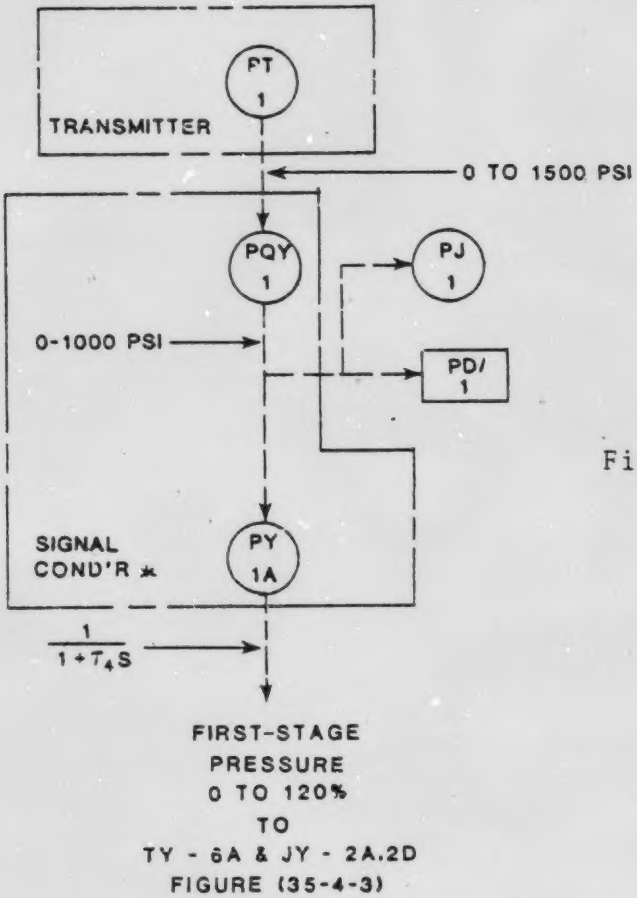

PT
1
TRANSMITTER
0 TO 1500 PSI
PQY
1
PJ
1
0-1000 PSI
PD/
1
SIGNAL
COND'R *
PY
1A
$\frac{1}{1+T_4S}$
FIRST-STAGE
PRESSURE
0 TO 120%
TO
TY - 6A & JY - 2A.2D
FIGURE (35-4-3)

Figure 35-4-4.
First-stage pressure
channel.

time constant t_4 by PY-1A. The output of module PY-1A inputs into the reactor control system as turbine power with a range of 0% to 120%. This conversion is possible because turbine power is linear with first-stage pressure.

The third and final parameter used by the reactor control system is reactor power as measured by the power-range neutron detectors. Four groups of detectors measure reactor power in units of 0% to 150%. The highest nuclear power measured by these four groups is used by the reactor control system —

- To control those rods dependent on highest neutron flux region in the reactor core for efficient use of fuel and prevention of hot spots.
- To prevent loss of control on loss of signal (fails low).
- To shut down the reactor on a failed high signal.

The highest nuclear power is determined by the auctioneer module JY-1 (Figure 35-4-3) and provides one input into the power-rate comparator channel. Turbine power, output of module PY-1A, provides the second input.

As illustrated in Figure 35-4-1, the power-rate comparator channel consists of three functional blocks — the rate comparator, nonlinear gain, and variable gain units. The rate comparator consists of the summer module JY-2A and rate module JY-2B. Summer JY-2A compares reactor power and turbine power and outputs an error in the range of -7.5% to +7.5%. To speed system response, rate module JY-2B provides an output that depends upon the rate of change of error. This power mismatch (error) is converted to a temperature error by the nonlinear gain unit JY-2C, which initiates control-rod motion in accordance with its gain characteristics given in Figure 35-2-4. The rates illustrated in Figure 35-2-4 are typically 0.3°F/%Δg and 1.5°F/%Δg for X and Y, respectively. The output of JY-2C is the temperature error with a range of -10°F to +10°F, which inputs into the variable gain unit.

The variable gain unit consists of the variable gain module JY-2D and divider JY-2E. The gain characteristics of module JY-2D were illustrated in Figure 35-2-5; they provide (1) adequate control of the reactor during lower-power operation by gaining the turbine power signal by two and (2) stable control of the reactor during high-power operation by inversely gaining turbine power to a gain of one. The output of module JY-2D, range 0%-100%, divides the temperature error (from module JY-2C) at the divider JY-2E. Power mismatch (output of JY-2E) is, therefore, the temperature error biased in accordance with turbine power, has a range of -10°F to +10°F, and provides one input into the error summer UY-1, as shown in Figure 35-4-3.

The temperature comparator channel consists of a proportional unit and summer (Figure 35-4-1). The proportional unit consists of two modules (Figure 35-4-3) — the proportional module TY-6A and L/L module TY-6B. Module TY-6A converts turbine power to a proportional temperature signal with high and low limits corresponding to full reactor power and hot shutdown temperatures, respectively, as graphed in Figure 35-4-5. Module TY-6B lags the temperature signal

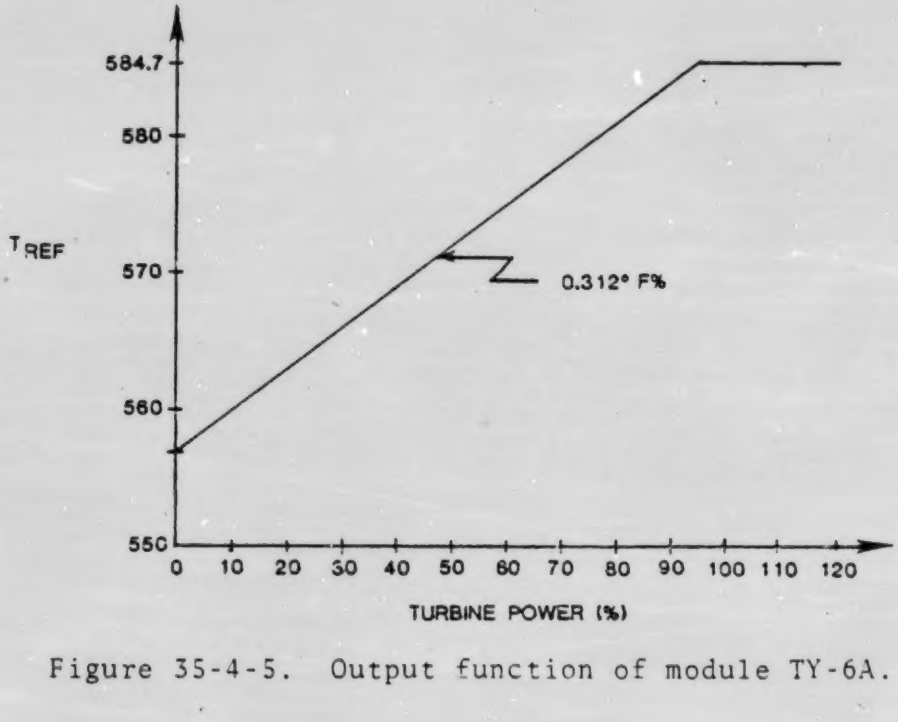


Figure 35-4-5. Output function of module TY-6A.

by t_6 seconds to filter inherent noise in the control system for stable control. The output of module TY-6B is the programmed T_{ref} with a range of 557°F to 584.7°F.

The summer TY-7 compares T_{ref} to T'_{avg} and produces a temperature deviation with a range of -10°F to +10°F.

This temperature deviation from the temperature comparator channel is compared to power mismatch from the power-rate comparator channel by the error summer UY-1. The output of module UY-1 is referred to as the "combined error" with a range of -10°F to +10°F and is used by the rod-speed controller and the rod in/out logic as in Figure 35-4-3.

The rod-speed controller consists of one module, the function generator SY-1A. Module SY-1A controls control-rod speed when in the automatic mode of operation by limiting lower and high stepping rates and acceleration dependent on the combined error. The output of module SY-1A (Figure 35-4-6) varies from 8 to 72 steps per minute based upon the combined error input.

The rod IN/OUT logic consists of two bistables — SB-1A and SB-1B. Module SB-1A is energized when the combined error reaches +1.5°F and above to actuate control-rod motion in the "OUT" direction. Module SB-1B is energized when the combined error reaches -1.5°F and below to actuate control-rod motion in the "IN" direction. Both modules have 0.5°F reset action.

Rod speed and direction are combined by the rod-speed module SY-1B to provide the rod-speed program for automatic operation (shown previously in Figure 35-2-6). Minimum and maximum speeds referred to are 8 and 72 steps per minute, respectively, with a speed gain of 32 steps per minute per °F. Figure 35-2-6 depicted the points at which bistables SB-1A and 1B are energized and reset and in which direction

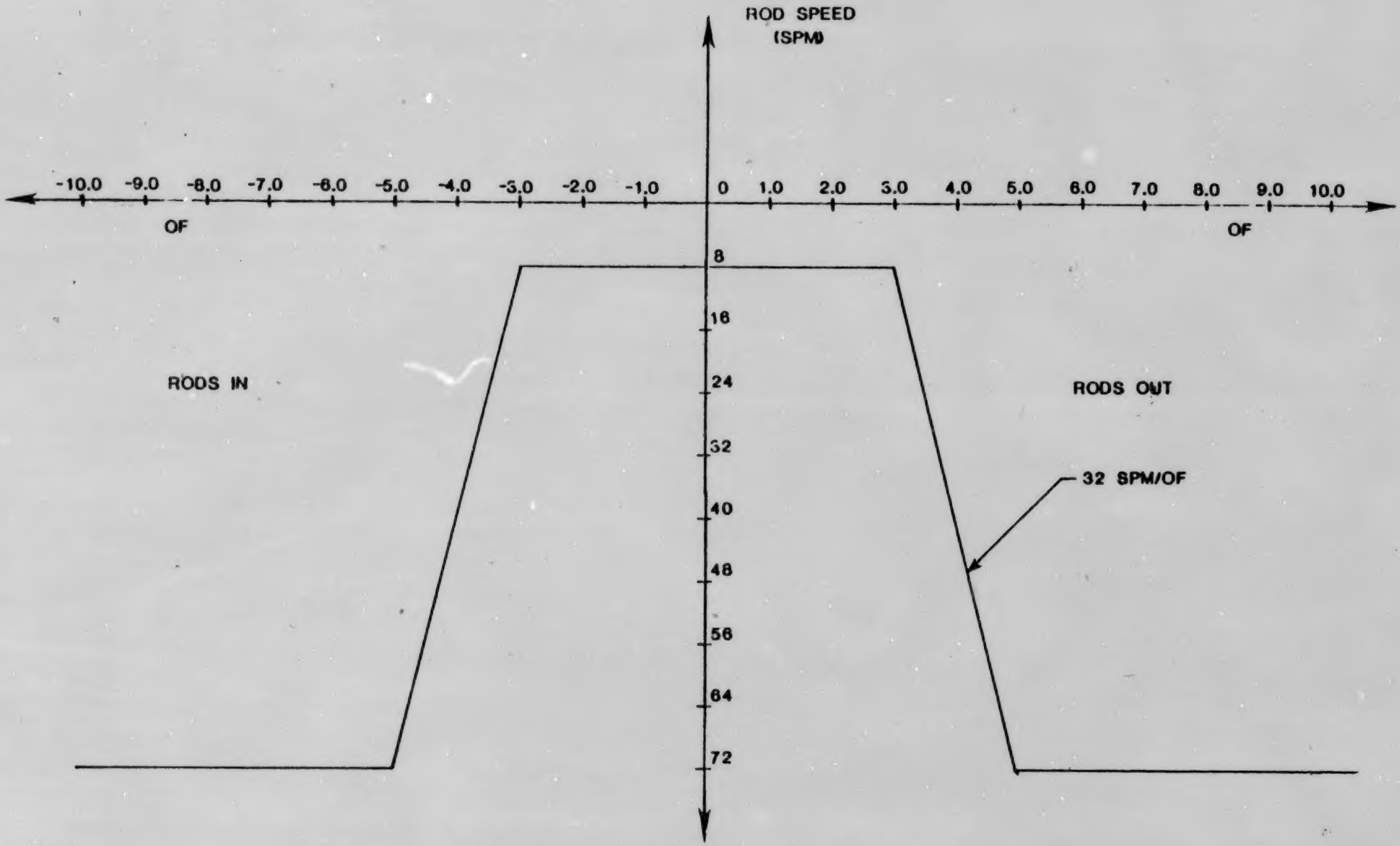


Figure 35-4-6. Output function of module SY-1A.

the control rods move, dependent on the combined error.

The rod-speed module SY-1B provides rod control in the manual mode of operation, as well as in the automatic mode of operation as previously discussed. Module SY-1B receives manual rod speeds and direction from the operator's panel. Minimum and maximum rod speeds selectable are 48 and 72 steps per minute (SPM). In addition, rod-speed indication is provided at the operator's panel in both automatic and manual modes of operation by the speed indicator SI-1, which has a range of 8 to 72 steps per minute. Speed and direction outputs from module SY-1B are provided to the rod-control system.

To illustrate how the reactor control system operates, a hypothetical condition will be used. Assume a steady-state condition in which both turbine and reactor power are at 25%; T_{avg} is 565°F; and the reactor coolant boron concentration remains unchanged. The operator commences a medium rate of turbine power ascension to 50%. The main turbine control valves begin opening to increase electrical power output and, therefore, to increase the turbine first-stage pressure. This increase in first-stage pressure causes a positive power error in the power rate comparator channel and a T_{ref}/T'_{avg} deviation in the temperature comparator channel since both reactor power and T_{avg}, respectively, are still at initial conditions.

Control-rod motion is initiated primarily by the power-rate comparator channel at this stage, for four reasons:

1. Module JY-2B leads the power error in accordance with the rate of change.
2. Since the power error would be greater than 1.0%, a larger temperature error would be provided the nonlinear gain unit, module JY-2C.

3. Turbine power would be gained by two (by the variable-gain unit JY-2D) because initial turbine power was below 50%.
4. The combined lag effect of modules PY-1A and TY-6B on T_{ref} initially produces a small deviation between T_{ref} and T'_{avg}.

Since more heat is being transferred in the steam generators because the turbine control valve has opened, colder reactor coolant is being returned to the reactor core. With movement of the control rods by the power-rate comparator channel and the colder water entering the core, reactor power increases following turbine power. Reactor power then begins to bias the power mismatch at module JY-2A to control withdrawal speed of the control rods. When turbine power reaches the 50% level, the power-rate comparator channel contributes less to control-rod motion (due to the derivative action of JY-2B) as reactor power reaches some equilibrium condition. At this point, the temperature-comparator channel assumes major control of control-rod motion to control T_{avg}. Any further motion of the control rods to compensate for a T_{ref}/T_{avg} deviation would have little effect on the power-rate comparator channel due to small rates of change in reactor power.

Returning to a steady-state condition at 50% turbine power, reactor power is controlled by the temperature comparator channel, which maintains T_{avg} at 572°F.

PRESSURIZER PRESSURE-CONTROL SYSTEM

The objective of the pressuizer pressure-control system, explained briefly in Module 35-2, is to maintain operating pressure of the reactor coolant system constant under all load conditions to provide –

- Prevention of departure from nucleate boiling (DNB) by maintaining system pressure above that corresponding to the saturation pressure for full-load coolant hot leg temperatures.
- Allowance for higher temperatures during load and overpower transient conditions.
- Means for ensuring a solid water heat transfer medium to conduct reactor-core test to the steam generator.

The pressurizer is utilized as the prime pressure measurement point of the reactor coolant system since it is least affected by flow-induced variations. Pressure transmitter PT-2 (Figure 35-4-7) senses a pressure in the range of 1700 psig to 2500 psig and converts this pressure to an electronic current signal. Loop power supply PQY-2 provides the necessary power supply to drive PT-2 and to convert its current signal to a proportional voltage. (PQY-2 was shown as the signal conditioner in Figure 35-2-9.) This pressure is displayed by the pressure indicator PI-2 located on the operator's panel and provided as an input to the plant computer by the input buffer PD/2.

As illustrated by Figure 35-4-7, the pressurizer pressure signal is provided to the pressure controller, which consists of modules PC-2A and PCY-2A. Module PC-2A is a proportional + integral + derivative controller that –

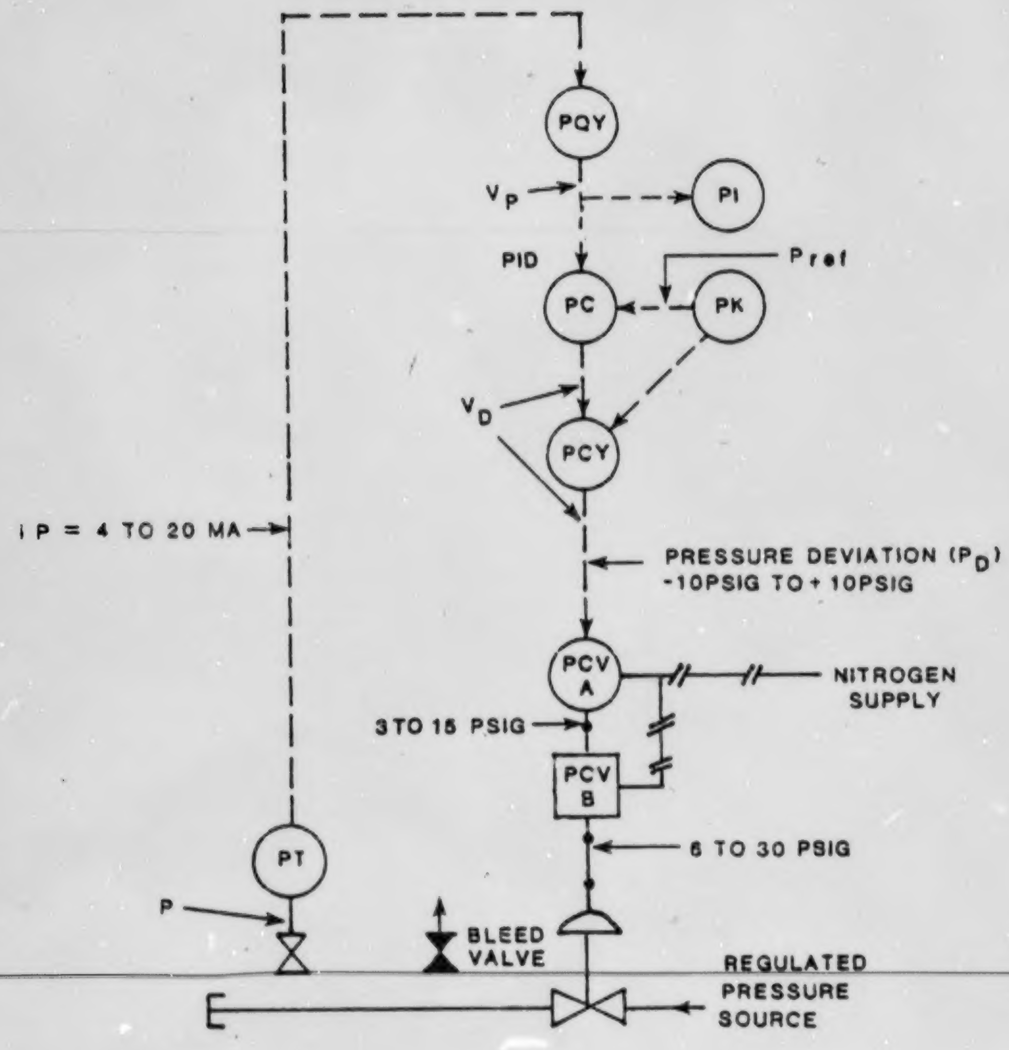

PQY
V P
PI
PID
P ref
PC
PK
V D
PCY
I P = 4 TO 20 MA
PRESSURE DEVIATION (P D)
-10PSIG TO + 10PSIG
PCV A
NITROGEN SUPPLY
3 TO 15 PSIG
PCV B
6 TO 30 PSIG
PT
P
BLEED VALVE
REGULATED PRESSURE SOURCE

Figure 35-4-7. Pressuirzer pressure-control system.

- Controls the final process controlling actuator(s) by deriving an output based on the deviation of the measured variable input, P_{act}, and the setpoint (when automatic mode), P_{ref}.
- Provides gain for the deviation signal.
- Provides lag in the deviation signal for system stability.
- Provides a quick response to a changing input signal.
- Tracks the deviation output signal of module PCY-2A in manual mode for a balanceless/bumpless transfer to automatic mode.

Module PC-2A has characteristic transfer function represented by Equation 35-4-1.

$$\text{Output} = G(Sp - IN)\left(1 + \frac{1}{\tau_I s} + \frac{s}{1 + \tau_D s}\right)$$

Equation 35-4-1
(Equation = Eq.)

where:

G = module gain.
Sp = setpoint.
IN = input pressure signal.
τ_I & τ_D = reset and rate time constant, respectively.

Output of module PC-2A corresponds to the pressure deviation (-100 psig to +100 psig) in Figure 35-4-7 and illustrated in the pressurizer pressure-control characteristic wave of Figure 35-2-10.

The controller driver, module PCY-2A, is mainly utilized to provide manual control capability by supplying an output deviation signal, regardless of the actual deviation mode of operation. However, module PCY-2A allows the actual deviation signal to be the controlling signal.

In conjunction with the pressure controller, the manual/auto (M/A) station PK-2A, located at the operator's panel, provides (1) the means to select automatic or manual control, (2) adjustment of the pressure setpoint, P_{ref}, for use in the automatic mode by module PC-2A to output a deviation signal based upon its comparison with the actual pressure, and (3) the controls for use in manual operation.

Pressurizer pressure deviation, output of module PCY-2A, is used to control the position of the pressurizer spray valve, to provide heat generation of the variable heaters, and to operate the normally closed power-relief valve.

The pressurizer spray valve control consists of the spray controller and its associated manual/auto station and the signal conditioner (as in Figure 35-2-9). The spray controller consists of the proportional controller PC-2B and the controller driver PCY-2B. Module PC-2B receives the pressure-deviation signal from module PCY-2A to generate a valve position demand signal based upon a pressure deviation of +25 psig to +100 psig corresponding to 0% to 100% valve position. (This pressurizer spray characteristic was illustrated in Figure 35-2-10.) Modules PCY-2B and PK-2B are used in the same manner as modules PCY-2A and PK-2A, respectively, providing automatic (based on a setpoint of +25 psig deviation) and manual control of pressurizer spray, with module PC-2B having tracking capability of PCY-2B output in manual mode, as well.

The signal conditioner consists of the current to pneumatic (I/P) converter, PCV-2B, and the signal modifier, PCV-2B1. Module PCV-2B receives the valve-position demand signal from PCY-2B and converts the signal to a proportional pneumatic air signal, which normally ranges from 3 psig to 15 psig. The pneumatic air signal then is used by module PCV-2B1 to output a 6-psig to 30-psig pneumatic air control signal to position the air-operated diaphragm valve. (A higher pressure signal is necessary to position the valve.)

Pressure bistable PB-2 actuates at +100 psig pressure deviation to energize relay PY/2, which opens the solenoid valve by energizing the solenoid, which, in turn, provides the necessary air pressure to open the power-relief valve. Module PB-2 will reset at 30-psig deviation and close the power-relief valve. (This sequence was illustrated in Figure 35-2-10.)

The pressurizer heater control consists of the heater controller and signal conditioner (Figure 35-2-9). The heater controller of the proportional module PC-2C (Figure 35-4-7), which receives the pressure deviation signal from module PCY-2A and output a heat-demand signal based on a pressure deviation of +15 psig to -100 psig to correspond to 0% to 100% heat kW output from the pressurizer heaters. This demand signal is received by a heater control unit (signal conditioner), which converts the signal to a proportional current signal and passes it through the heater elements to generate the heat required. The control unit basically consists of circuit breakers for isolation of heater elements, transformers to obtain the proper current drive, and overload devices for protection against short circuits. (The characteristic proportional heat output based on pressurizer pressure deviation was indicated in Figure 35-2-10.)

During normal steady-state operation, the pressurizer pressure control system will automatically control the variable heaters to compensate for minor pressure fluctuations from P_{ref}. The variable heaters are half on during this mode

(Figure 35-2-10). As the reactor coolant system pressure drops below P_{ref}, the variable heaters will gradually increase their kW output to increase system pressure until the heaters are full on at -15 psig pressure deviation. Although not previously discussed, the backup pressurizer heaters would energize to compensate for a further drop in pressure equal to a deviation from P_{ref} of -25 psig. This actuation would be provided by a pressure bistable with a setpoint and reset of -25 psig and -17 psig, respectively, similar to that used for actuation of the power-relief valve. The backup heaters would de-energize when pressure deviation increased beyond -17 psig, where pressure control would be transferred back to the variable heaters.

As reactor coolant system pressure increases beyond P_{ref}, the variable heater kW output will decrease until de-energization (full off) at a pressure deviation of +15 psig. Since a steam bubble is maintained in the pressurizer, any increase in system pressure would require less heat to be generated by the variable heaters. With pressure increasing beyond the deviation of +15 psig, the pressurizer spray valves are proportionally modulated above a pressure deviation of +25 psig until fully opened at +75-psig deviation. Proportional spray allows steam in the pressurizer steam bubble to condense, thereby compensating for pressure increases. If pressure continued to increase despite full pressurizer spray, the power-relief valve would be opened at a +100-psig deviation from P_{ref}. This actuation would allow pressure to be relieved from the system to the pressurizer relief tank. The power-relief valve then would close when system pressure dropped below the deviation pressure of +80 psig, whereby the proportional spray would assume pressure control until the variable heaters reassumed system pressure control and until steady-state operation again was maintained.

During the sequence of pressurizer pressure control just explained, both manual/auto stations PK-2A and 2B were in automatic mode with setpoints at P_{ref} and +25-psig deviation, respectively. If M/A station PK-2A were to be placed in manual mode, a deviation signal would be generated by module PCY-2A, irrespective of actual deviation from P_{ref}, at command from PK-2A. The pressurizer spray valve would be positioned, the power-relief valve would be opened, and the pressurizer variable heater would generate the required heat according to the setting manually selected. This sequence would follow the same characteristic curve in Figure 35-2-10. In addition, the output of PCY-2A would be tracked by module PC-2A in order that the output of PC-2A equals that of PCY-2A. This tracking provides for a balanceless/bumpless transfer to automatic mode when initiated.

If M/A station PK-2B were placed in manual mode while PK-2A remained in automatic mode, a position signal would be generated by module PCY-2A at command from PK-2B, regardless of actual position demand, based upon pressure deviation from PCY-2A. Although the pressurizer spray valve can be positioned as desired, both the power-relief valve and the pressurizer variable heater would remain in automatic control. Module PC-2B tracks the output of PCY-2B in this mode of operation to provide a balanceless/bumpless transfer back to automatic mode.

If both M/A stations PK-2A and 2B were placed in manual mode, PK-2A would provide manual control of the power-relief valve and pressurizer variable heater only while manual control of the pressurizer spray valve would remain with PK-2B.

EXERCISES

1. Explain the importance of process-control loops and devices. Under the supervision of instructor conduct a class discussion on this topic.
2. From the general data presented in this module, describe how instrumentation and control technicians can contribute to the safe operation of a nuclear power plant.

MATERIALS

One pressure transmitter, 4-mA to 20-mA output with pressure gage compatible with pressure-control valve selected.

The following items should be of the same make and model:

- One-loop power supply, +40 volts d.c., with signal converter if not integral with power supply.
- One proportional + integral + derivative controller with associated drives if not integral with controller.
- One manual/auto station.

One pressure indicator compatible with the voltage output of pressure transmitter and with scale range to match range of pressure transmitter.

One pressure-control valve with associated I/P converter and valve positioner.

Nitrogen supply bottle, 100 psig.

Pressure source, regulated, compatible with pressure-control valve selected.

One instrument valve and one bleed valve.

Tubing, 1/4", for control valve I/P converter and positioner nitrogen supply connection.

Piping, sized to fit control-valve requirements.
Wiring, #18 AWG.
Digital multimeter.
Deadweight tester with range of 0 psig to 100 psig.

PROCEDURES

1. Using all but the last two items in the Materials section, construct the control loop depicted in Figure 35-4-8. Do not connect pressure source at this time.
2. Using deadweight tester to apply pressure on the transmitter, align control loop to provide proper outputs for each module and valve position while in automatic mode. From the characteristic transfer function given previously for a PID controller, assume reset time τ_I = 150 sec, and rate time τ_D = 10 sec. Select the setpoint (P_{ref}) as desired to be compatible with the control system.

   Select controller gain during alignment to avoid saturation of controller amplifiers. The control valve should be aligned in such a manner that it is fully open for a +10-psig deviation and fully closed for a -10-psig deviation. Record information required in Data Tables 35-4-1 and 35-4-2.
3. Place control system in manual control at the M/A station (PK). Fully close control valve.
4. Ensure that bleed valve is fully closed.
5. Connect pressure transmitter to the process.
6. Connect pressure source to the process.
7. Open the bleed valve slightly.

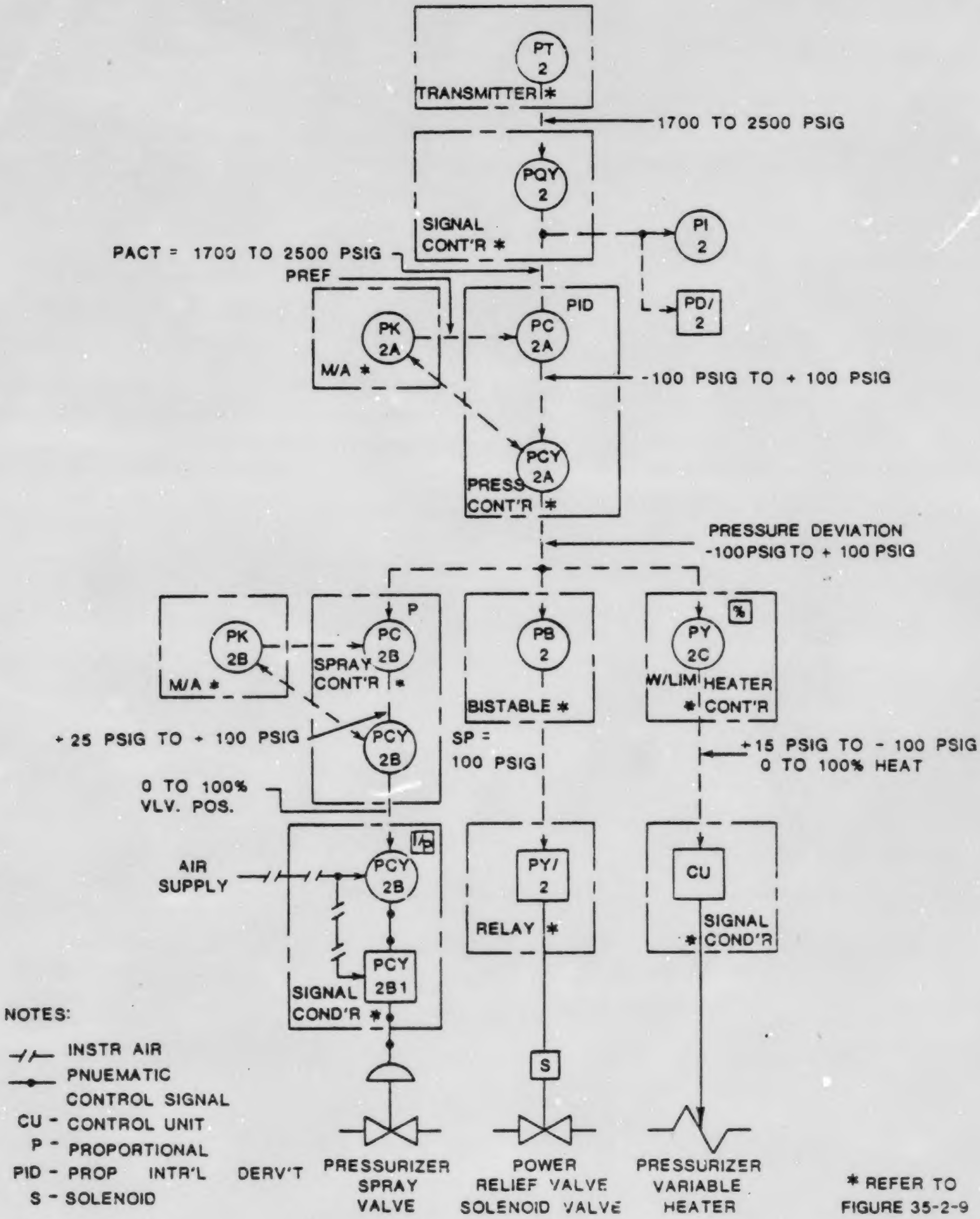

PT
2
TRANSMITTER *
1700 TO 2500 PSIG
PQY
2
SIGNAL
CONT'R *
PI
2
PD/
2
PACT = 1700 TO 2500 PSIG
PREF
PK
2A
M/A *
PC
2A
PID
-100 PSIG TO + 100 PSIG
PCY
2A
PRESS
CONT'R *
PRESSURE DEVIATION
-100PSIG TO + 100 PSIG
PK
2B
M/A *
PC
2B
P
SPRAY
CONT'R *
+25 PSIG TO + 100 PSIG
PCY
2B
0 TO 100%
VLV. POS.
PB
2
BISTABLE *
SP =
100 PSIG
PY
2C
%
W/LIM
HEATER
* CONT'R
+15 PSIG TO - 100 PSIG
0 TO 100% HEAT
AIR
SUPPLY
PCY
2B
I/P
PCY
2B1
SIGNAL
COND'R *
PY/
2
RELAY *
CU
SIGNAL
* COND'R
S
NOTES:
INSTR AIR
PNUEMATIC
CONTROL SIGNAL
CU - CONTROL UNIT
P - PROPORTIONAL
PID - PROP INTR'L DERV'T
S - SOLENOID
PRESSURIZER
SPRAY
VALVE
POWER
RELIEF VALVE
SOLENOID VALVE
PRESSURIZER
VARIABLE
HEATER
* REFER TO
FIGURE 35-2-9

Figure 35-4-8. Experimental control loop.

8. Place M/A station in automatic; observe control valve position itself to maintain a discharge pressure at the setpoint pressure selected.
9. Vary position of the bleed valve, watching the response of the control valve in maintaining pressure. Record findings in Data Table 35-4-3.
10. Position bleed valve to a half-open setting; place the M/A station in manual mode.
11. Position control valve as desired; observe the pressure vary according to position selection. Record findings in Data Table 35-4-4.
12. Return to automatic mode; observe the control valve as it responds to return discharge pressure at setpoint.

DATA TABLES

DATA TABLE 35-4-1

P (psig)	Ip (ma)	Vp (volts)
	4	
	8	
	12	
	16	
	20	

DATA TABLE 35-4-2

Po (psig)	Vp (volts)	PCV-A (psig)	PCV-B (psig)	Valve Position %
-10		3	6	0
- 5		6	12	25
0		9	18	50
+ 5		12	24	75
+10		15	30	100

DATA TABLE 35-4-3

Automatic	
Bleed Vlv Position	Control Vlv Position
Closed	
1/4	
1/2	
3/4	
Open	

DATA TABLE 35-4-4

Manual (Bleed Vlv ½ Open)	
Control Vlv Position	Discharge Pressure
Closed	
1/4	
1/2	
3/4	
Open	

REFERENCE MATERIALS

Considine, D.M., ed. *Process Instrumentation and Controls Handbook*. 2nd ed. New York: McGraw-Hill Book Company, 1974.

Johnson, C.D. *Process Control Instrumentation Technology*. New York: John Wiley & Sons, 1977.

Nay, J.A. *Topical Report - Process Instrumentation for Westinghouse Nuclear Steam Supply Systems (4 Loop Plants*. Pittsburgh: Westinghouse Electric Corporation, 1971.

NOTE: Test items 1-5 are based upon one of the Exercises in Module 35-2. That exercise stated, "Sketch the block diagram of an instrument and control system that measures reactor coolant flow and is monitored by indication and computer printout at the operator panel (control board)." Sketch this diagram again for the present Test, making the following modifications and answering the following questions.

1. Draw the control-loop diagram assuming a 0-gpm to 100,000-gpm flow measurement by the flow transmitter and bistable actuations as 92% and 90% flow for alarming and reactor trip, respectively.

2. Describe the function of each module in a block and the output ranges associated with each module.

3. Explain the dynamic behavior of the loop when system flow drops below normal operating conditions.

4. Would a square root extractor be necessary in this loop? Explain.

5. What type of scale is used on the flow indicator?

6. Explain the purpose of each of the following control systems:

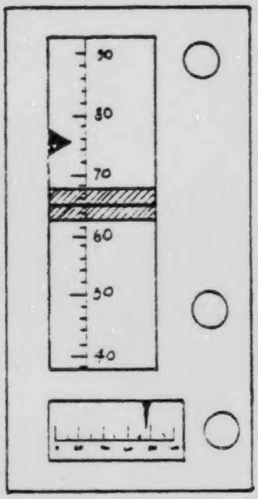
   a. Reactor control system.

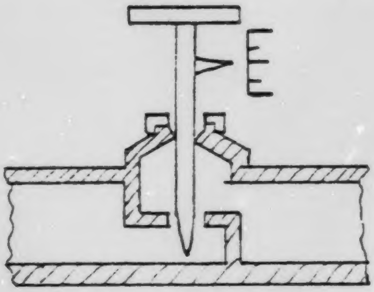
   b. Pressurizer control system.

NUCLEAR TECHNOLOGY

MODULE 35-5

CATHODE-RAY TUBE SYSTEMS (CRT)





SYSTEMS AND COMPONENTS

COURSE 35

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

CONTENTS

COURSE 35 SYSTEMS AND COMPONENTS

MODULE 35-1 Electrical Distribution

MODULE 35-2 Instrumentation and Control for Major Plant Components

MODULE 35-3 Recording and Display Devices

MODULE 35-4 Process Control Loops and Devices

MODULE 35-5 Cathode-Ray Tube Systems (CRT)

MODULE 35-6 Preventive Maintenance for Systems and Components

MODULE 35-7 Instrument Reliability

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INTRODUCTION

This module discusses the fundamentals of cathode-ray tube (CRT) systems and their use to monitor, alarm, control, and display engineering data concerning power plant operation.

The basic CRT (Figure 35-5-1) consists of an electron gun (heater and cathode); anode (grids) for focus, brightness and blanking; deflection yoke with horizontal and vertical deflection plates; and an aquadag-coated tube with luminescent screen.

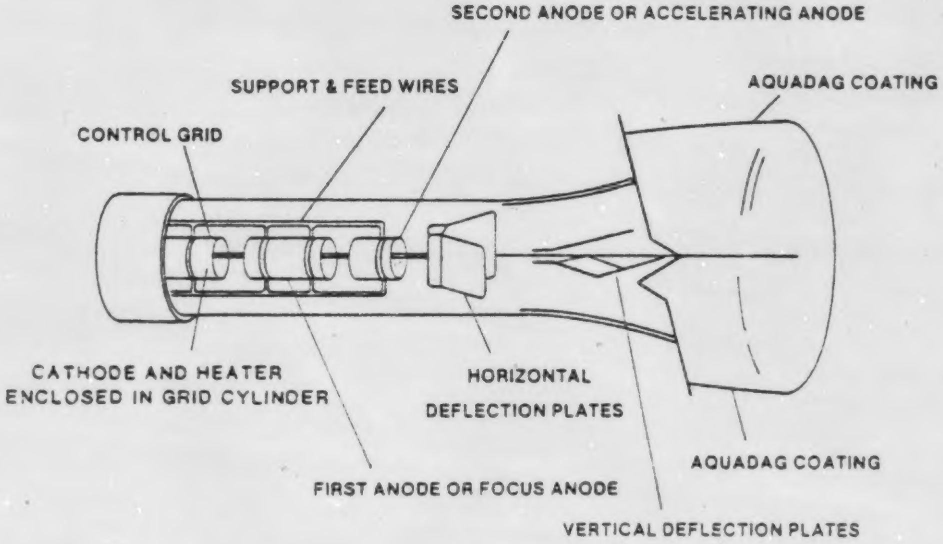

SECOND ANODE OR ACCELERATING ANODE
SUPPORT & FEED WIRES
AQUADAG COATING
CONTROL GRID
CATHODE AND HEATER ENCLOSED IN GRID CYLINDER
HORIZONTAL DEFLECTION PLATES
AQUADAG COATING
FIRST ANODE OR FOCUS ANODE
VERTICAL DEFLECTION PLATES

Figure 35-5-1. Cathode-ray tube.

The CRT displays a visible pattern by focusing an electron beam to a small cross section on the luminescent screen and varying the intensity and position of the beam across the screen in a sequential manner in an infinitesimal period.

The digital, video, and graphical CRT systems contain CRT's that operate in the same basic manner, although each system utilizes additional distinct components to produce its respective displays.

MODULE PREREQUISITES

The student should have completed Course 5, "Introduction to Nuclear Systems"; Course 10, "Power Plant Systems"; and the previous modules of this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
    - CRT.
    - Electron gun.
    - Anode.
    - Alphanumeric characters.
    - Raster.
    - Keyboard.
    - Composite video signal.
    - Noncomposite video signal.
    - Deflection.
    - Color graphics.
    - Convergence.
    - Cursor.
    - Coded symbols.
    - Digital display.
2. Functionally describe, with the aid of block diagrams, the three CRT systems.
3. List advantages and disadvantages of CRT systems over conventional means.
4. List applications of each CRT system.

DIGITAL CRT SYSTEM

The digital CRT system provides a communications link between the operator and the computer system or processor for use as an input/output (I/O) terminal for entering, displaying, and editing alphanumeric data. The operator communicates with the processor by use of a keyboard having associated interface and control logic for editing and verifying data prior to transmission to the processor. Communication from processor to operator is provided by the display device (CRT) with associated control logic to drive the display and by an interface to the processor.

The CRT system is divided into four modules, as illustrated in the simplified block diagram of Figure 35-5-2. These modules are the video monitor, display control, interface, and power supply.

VIDEO MONITOR

The video monitor provides visual communication capability to the operator for transactions with the processor. It consists of an electromagnetically deflected CRT display and associated video drives (explained in a later section). The monitor displays alphanumeric characters through the use of a system of parallel lines known as the "raster." The display control logic (covered in the next section) illuminates discrete patterns (dots) on the raster as determined by line, character, and dot position parameters.

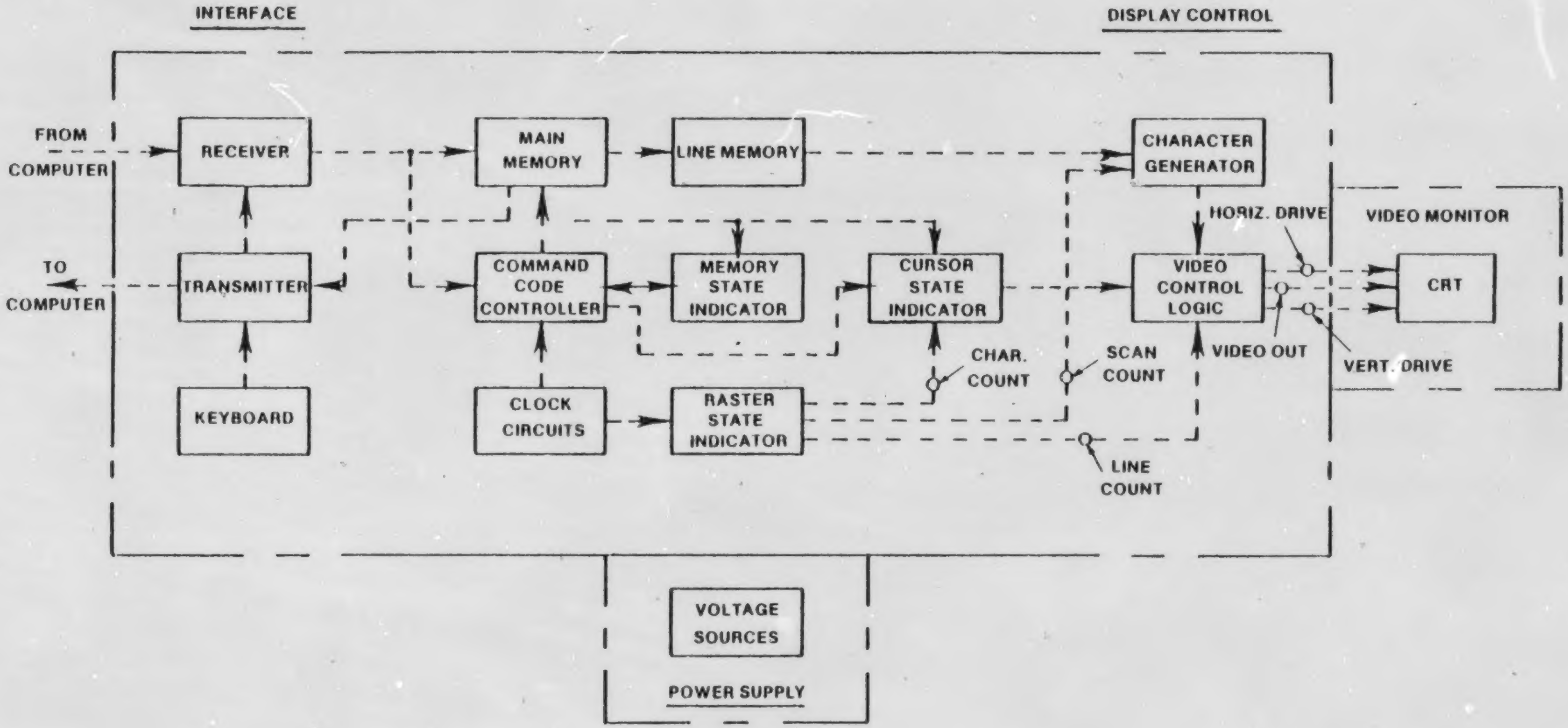

INTERFACE
DISPLAY CONTROL
FROM COMPUTER
TO COMPUTER
RECEIVER
TRANSMITTER
KEYBOARD
MAIN MEMORY
LINE MEMORY
COMMAND CODE CONTROLLER
MEMORY STATE INDICATOR
CURSOR STATE INDICATOR
CLOCK CIRCUITS
RASTER STATE INDICATOR
CHARACTER GENERATOR
VIDEO CONTROL LOGIC
HORIZ. DRIVE
VIDEO OUT
VERT. DRIVE
CHAR. COUNT
SCAN COUNT
LINE COUNT
VIDEO MONITOR
CRT
VOLTAGE SOURCES
POWER SUPPLY

Figure 35-5-2. Digital CRT system.

Typically, the raster consists of 240 horizontal lines, each with 560 dot positions across the screen. A character is represented by a 7 x 10 dot matrix, as illustrated in Figure 35-5-3. Spacing, margins and cursor position are provided for in this matrix for each character. The horizontal and vertical deflection circuits are synchronized and triggered by the display control logic to intensify dot positions or to hold at low enough an intensity to leave no visible trace on the screen. This illumination of dots in the 7 x 10 dot matrix generates the alphanumeric characters on the screen. Each character is scanned 10 times (for a total of 240 horizontal scans) for each vertical scan. The matrix and scanning capability displays 24 lines of alphanumeric characters, 80 characters in width.

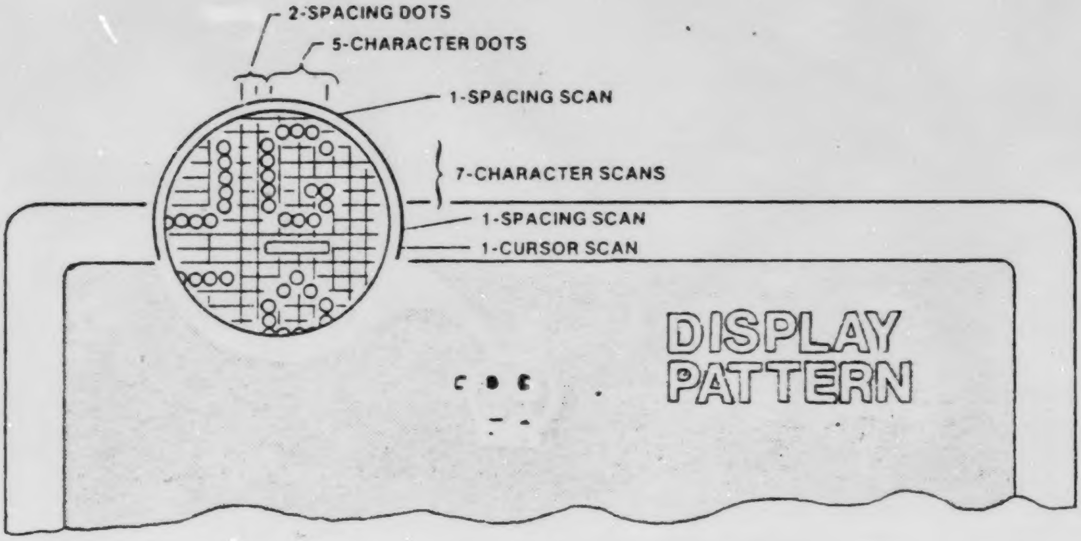

2-SPACING DOTS
5-CHARACTER DOTS
1-SPACING SCAN
7-CHARACTER SCANS
1-SPACING SCAN
1-CURSOR SCAN
DISPLAY
PATTERN

Figure 35-5-3. Display pattern.

DISPLAY CONTROL

The display control receives data from the interface module as indicated in Figure 35-5-2, interprets command codes, stores character codes in memory, and returns data to the interface module when necessary. In addition, it controls the raster, triggers the monitor, and continually refreshes the CRT screen as determined by proper command codes stored in memory. To perform these functions, the display control consists of the following:

- Raster state indicator.
- Main and line memories.
- Memory state indicator.
- Cursor position indicator.
- Video control logic w/character generator.
- Command code controller.

The raster state indicator consists of a series of counters that synchronize the display control and video monitor for proper display of alphanumeric data. As illustrated in Figure 35-5-3, the display consists of 24 lines, 80 characters wide, with each character field consisting of a 7 x 10 dot matrix. Therefore, dot, character, line, and scan counters are used for the synchronization required.

Memory consists of two sections – the main memory and line memory – both of which consist of shift registers. The main memory is loaded from the interface module (to be discussed later) and stores a number of characters for refreshing the video screen through the use of the line memory, which stores all the characters in the line being displayed. The line memory then outputs this data to the character generator for display via the video control logic.

Many commands to insert characters and position the cursor depend upon the position of the first, last, and zero (unused) lines in main memory. To provide this capability, the memory state indicator tracks the last character position in each line and the first, last, and zero lines in main memory and, in addition, preserves the relationship of every line stored in memory to its correct position on the display.

To allow new data to be entered in memory and to be displayed, the cursor position indicator tracks the position of the cursor in main memory and generates a command signal to the video control logic to display a blinking underscore on the video screen at the point at which a new character may be entered.

The video control logic consists of vertical and horizontal drive logic with an associated character generator to determine the proper video signal. The video signal to the monitor is derived in a read-only memory (ROM), called the "dot character generator," which receives the code and scan count for the character to be plotted. The ROM then generates the proper video signal for the character and scan.

The display command-code controller is utilized to control the entering of data and mode of operation, and to perform editing functions. This control is accomplished by receiving character codes, decoding them, and performing the specified functions, writing all character codes into main memory, allowing the cursor movement functions, and performing the required editing functions such as CLEAR.

INTERFACE

The interface consists of a keyboard and receiver/transmitter (Figure 35-5-2). It controls the flow of data between display control, computer, and operator.

The keyboard (refer to Figure 35-5-4a) typically is a mechanically-switched encoded device that consists of an array of intersecting signal lines. The array consists of x- and y-lines as shown in Figure 35-5-4b. When a key is depressed, its corresponding x- and y-lines intersect, creating a nodel point which the scanner detects by forcing a low-voltage signal on the x-line and searching for a low voltage on the corresponding y-line. Since the counter causes the scanner to check sequentially each node, the scanning array is arranged in such a manner that the counter value that selects each node equals the code for the alphanumeric character assigned to the key at that node. Therefore, when a completed circuit is detected by the scanner, the value of the counter is sent to the transmitter.

The receiver/transmitter in the interface module provides the direct means of communication with the computer. Data received from the computer is conditioned for use by the display control and sent to the command code controller for decoding and to the main memory for storage.

The transmitter receives data from the keyboard and main memory. This data is conditioned to a suitable form for use by the computer when sent by the transmitter. The data also is sent to the receiver of the interface module to complete the line of communication with the computer.

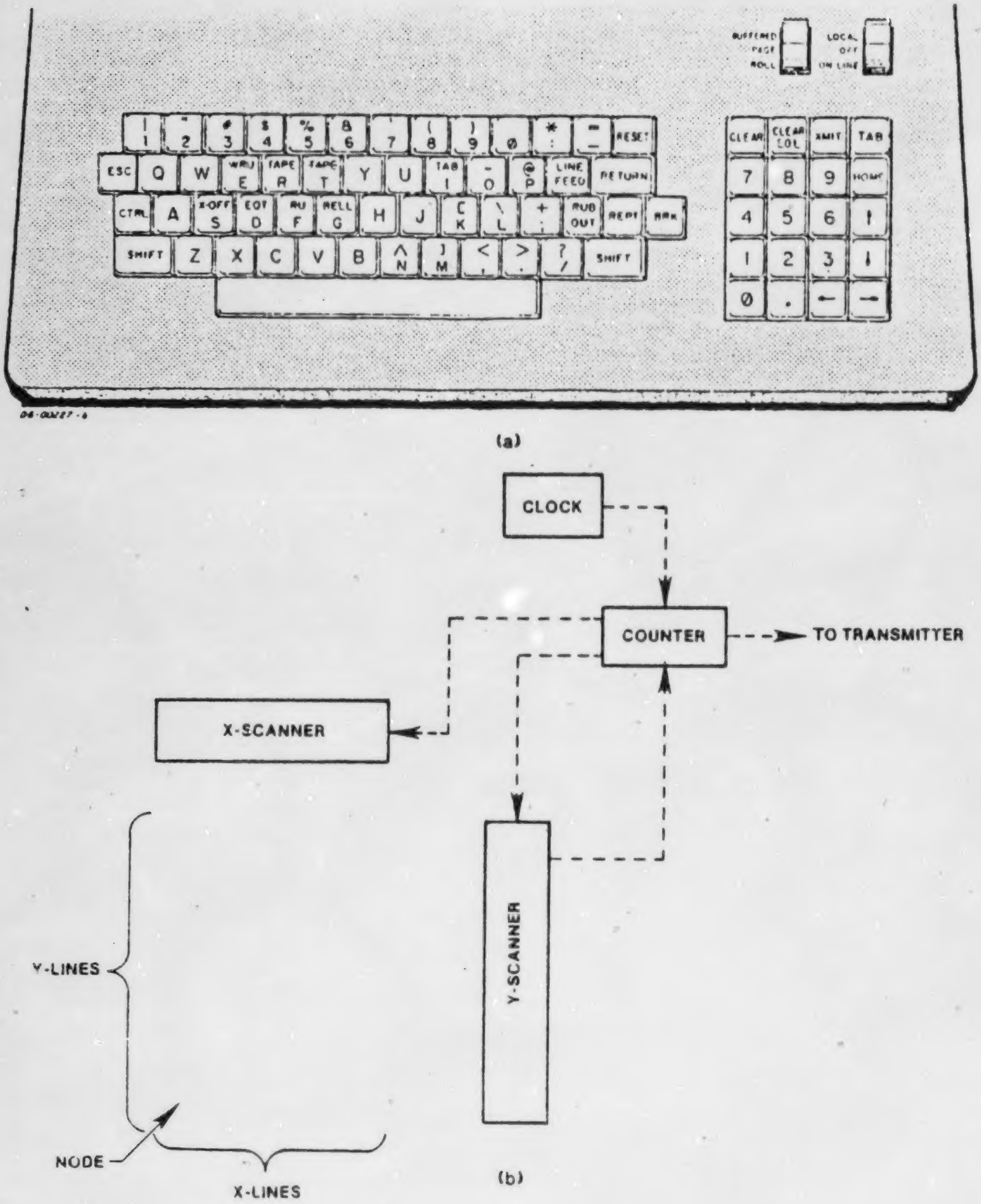

BUFFERED
PAGE
ROLL
LOCAL
OFF
ON LINE
RESET
ESC
WRU
TAPE
TAB
LINE FEED
RETURN
CTRL
X-OFF
EOT
RU
BELL
RUB OUT
REPT
BRK
SHIFT
CLEAR
CLEAR LOL
XMIT
TAB
HOME
06-00227-6
(a)
CLOCK
COUNTER
TO TRANSMITTER
X-SCANNER
Y-SCANNER
Y-LINES
NODE
X-LINES
(b)

Figure 35-5-4. Keyboard layout and diagram.

POWER SUPPLY

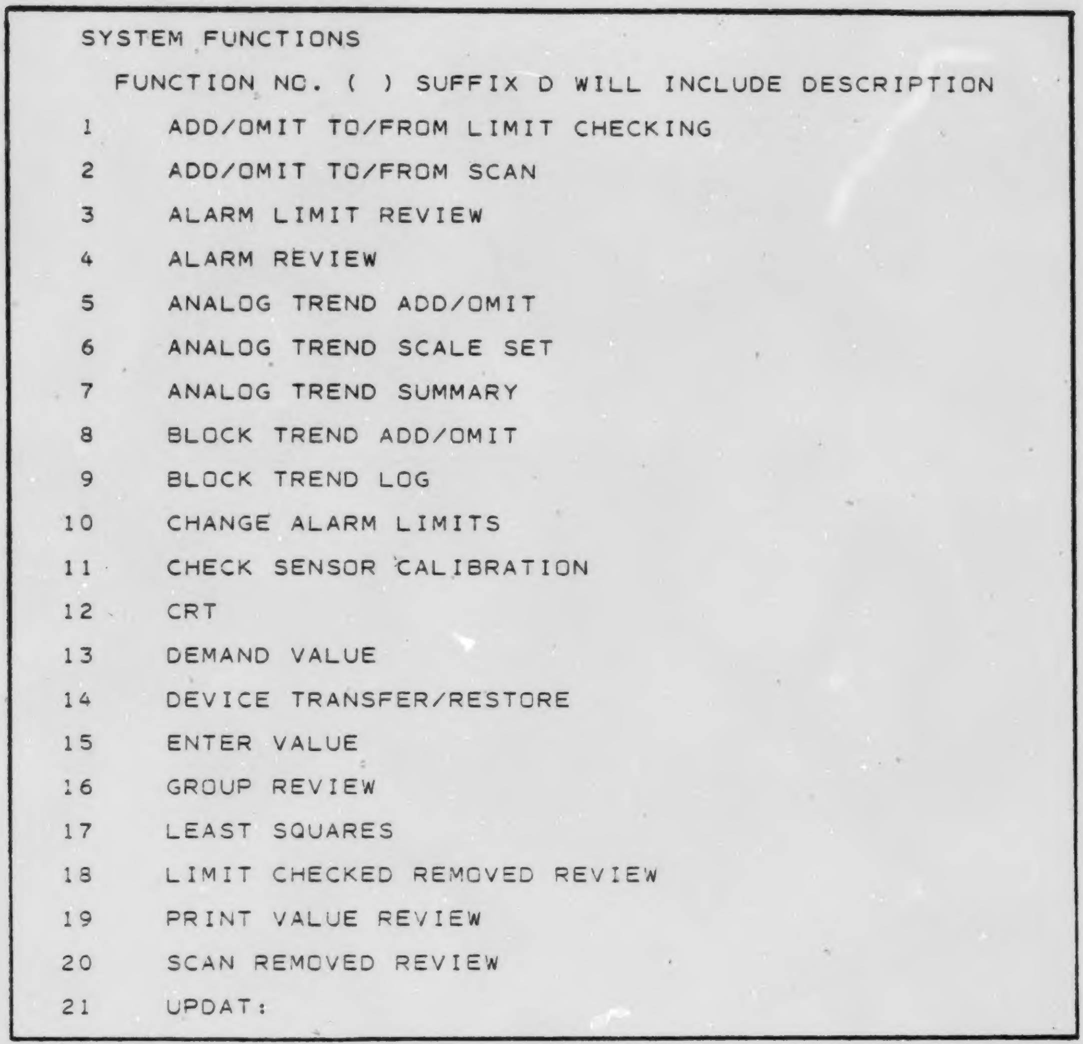
Typically, the power supply module, as illustrated in Figure 35-5-2, converts a.c. power (ROVAC, 50 or 60 Hz) to the required low-voltage d.c. power necessary for operation of the logic circuits and the monitor. Several d.c. voltage sources are used for the application involved. In addition, the power supply consists of regulators and overvoltage and overcurrent protection.

APPLICATION

In the process industry, the digital CRT system displays plant process conditions for operator use in the control of plant process systems. By use of the keyboard, the operator requests such displays from the computer. A menu or menus are displayed for the operator to select the desired function required, whether it be an alarm review, alarm limit review, demand value, etc. A typical menu is presented in Figure 35-5-5.

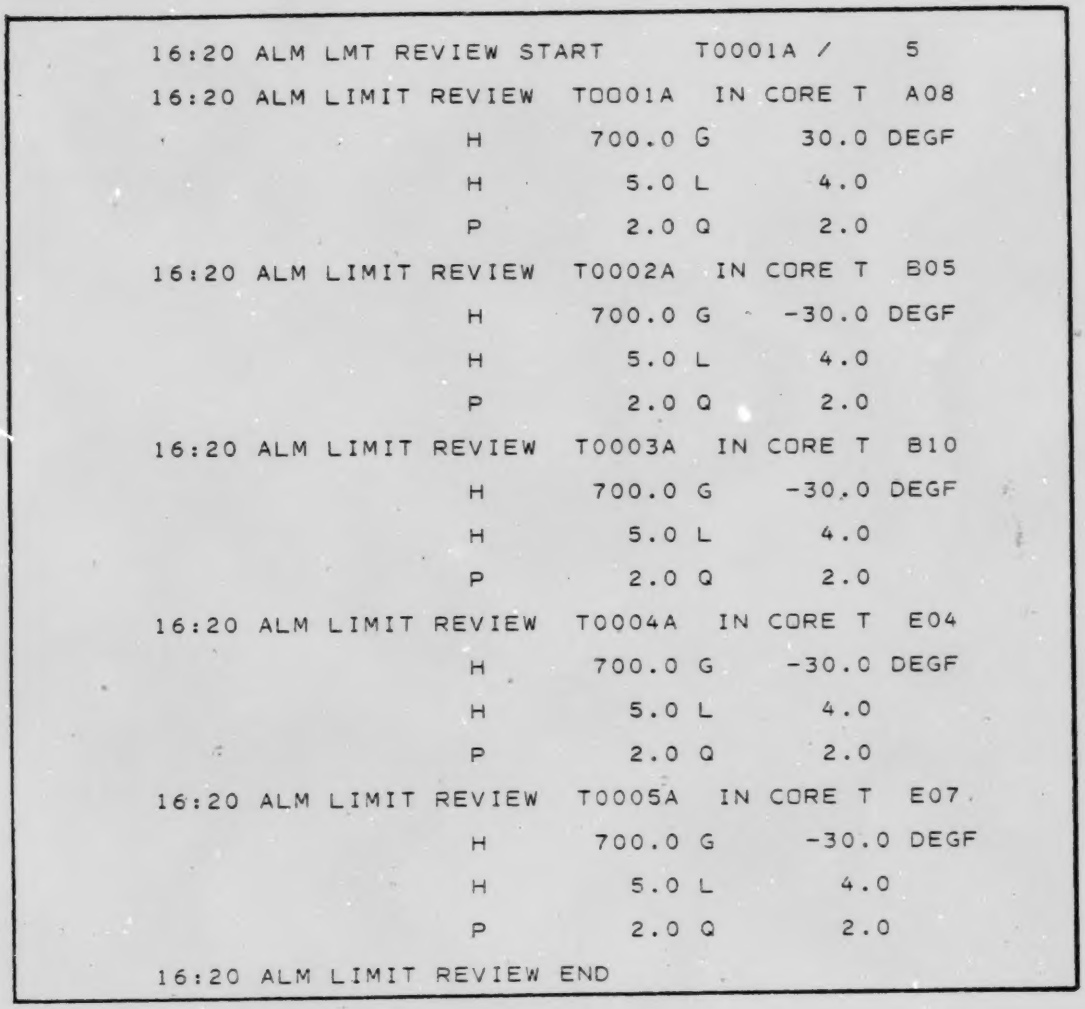
For the selection of item #3, "ALARM LIMIT REVIEW" for five reactor incore thermocouple readings, the computer would display on the CRT the digital data in Figure 35-5-6. The display typically is formatted to shown the following information for each point (reading) selected:

- Time.
- Function selected.
- Point identification.
- Description.
- High limit.
- Low limit.
- Engineering units.



```
  SYSTEM FUNCTIONS
    FUNCTION NO. (  ) SUFFIX D WILL INCLUDE DESCRIPTION
  1     ADD/OMIT TO/FROM LIMIT CHECKING
  2     ADD/OMIT TO/FROM SCAN
  3     ALARM LIMIT REVIEW
  4     ALARM REVIEW
  5     ANALOG TREND ADD/OMIT
  6     ANALOG TREND SCALE SET
  7     ANALOG TREND SUMMARY
  8     BLOCK TREND ADD/OMIT
  9     BLOCK TREND LOG
 10     CHANGE ALARM LIMITS
 11     CHECK SENSOR CALIBRATION
 12     CRT
 13     DEMAND VALUE
 14     DEVICE TRANSFER/RESTORE
 15     ENTER VALUE
 16     GROUP REVIEW
 17     LEAST SQUARES
 18     LIMIT CHECKED REMOVED REVIEW
 19     PRINT VALUE REVIEW
 20     SCAN REMOVED REVIEW
 21     UPDAT:
```

Figure 35-5-5. System master menu.



```
16:20 ALM LMT REVIEW START      T0001A /     5
16:20 ALM LIMIT REVIEW   T0001A   IN CORE T  A08
                   H        700.0 G      30.0 DEGF
                   H          5.0 L       4.0
                   P          2.0 Q       2.0
16:20 ALM LIMIT REVIEW   T0002A   IN CORE T  B05
                   H        700.0 G     -30.0 DEGF
                   H          5.0 L       4.0
                   P          2.0 Q       2.0
16:20 ALM LIMIT REVIEW   T0003A   IN CORE T  B10
                   H        700.0 G     -30.0 DEGF
                   H          5.0 L       4.0
                   P          2.0 Q       2.0
16:20 ALM LIMIT REVIEW   T0004A   IN CORE T  E04
                   H        700.0 G     -30.0 DEGF
                   H          5.0 L       4.0
                   P          2.0 Q       2.0
16:20 ALM LIMIT REVIEW   T0005A   IN CORE T  E07
                   H        700.0 G       -30.0 DEGF
                   H          5.0 L         4.0
                   P          2.0 Q         2.0
16:20 ALM LIMIT REVIEW END
```

Figure 35-5-6. Alarm limit review output on CRT.

For the display shown, T0001A through T0005A, are the points with their description to the right of each and the codes shown having the following interpretations: T – thermocouple; H – High limit (first line) and High incremental limit (second line); G – Low limit; L – Low increment limit; P – High limit dead band; Q – Low limit dead band.

VIDEO CRT SYSTEMS

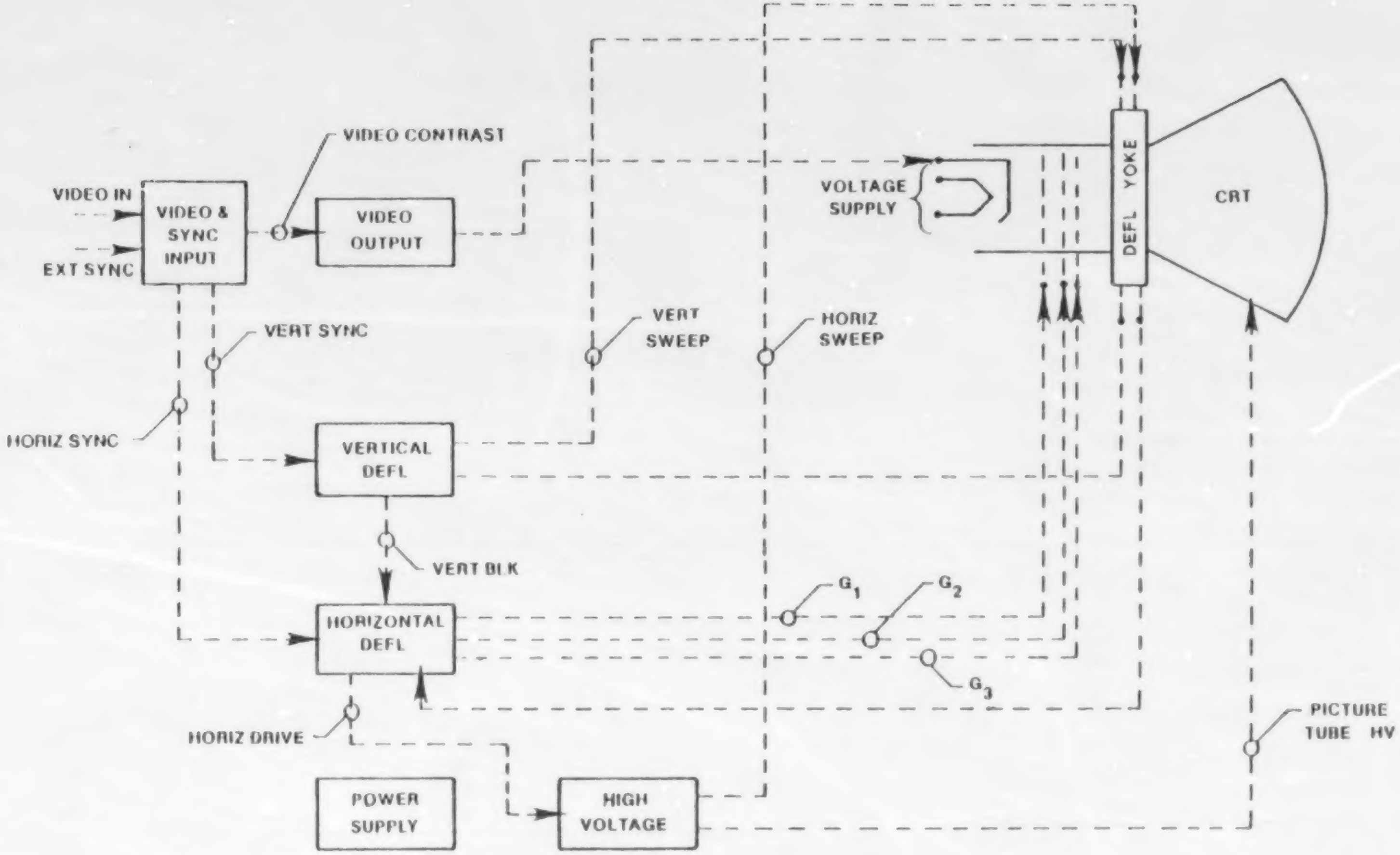
The video CRT system is used mainly in broadcast and industrial television applications. Through proper interfacing, this sytem can display alphanumeric data. However, the system described will be based upon reception of video analog signaling employed in television applications. No keyboard is associated with this system because it is used basically for displaying a visual picture of an area, process, etc. for the operator.

The CRT system is divided into five modules, as in Figure 35-5-7. The five modules are the video and sync input, video output, vertical and horizontal deflection, high-voltage supply, and power supply.

VIDEO AND SYNC INPUT

The video and sync input receives video signals, with or without external sync signals. External sync signals are received in two ways: (1) as a noncomposite signal separate from the video signal or (2) as a composite part of the video signal. For reception of composite video signals, the external sync input is grounded.

The input module amplifies the video signal received and supplies it to the video output module for contrast control. The sync signal utilized – whether composite, external, or internal – also is amplified and applied to the sync separator, which generates the vertical and horizontal sync signals. The sync signals then are supplied to the respective vertical and horizontal deflection modules.


VIDEO IN
EXT SYNC
VIDEO & SYNC INPUT
VIDEO CONTRAST
VIDEO OUTPUT
VOLTAGE SUPPLY
DEFL YOKE
CRT
VERT SYNC
VERT SWEEP
HORIZ SWEEP
HORIZ SYNC
VERTICAL DEFL
VERT BLK
HORIZONTAL DEFL
G_1
G_2
G_3
HORIZ DRIVE
PICTURE TUBE HV
POWER SUPPLY
HIGH VOLTAGE

NOTE: G_1 — BRIGHTNESS & VERT. BLK.
G_2 — SCREEN REG. (ADJ.)
G_3 -- FOCUS

Figure 35-5-7. Video CRT system.

VIDEO OUTPUT

The video output section receives the video signal from the video and sync module and amplifies it to a level sufficient to directly drive the picture-tube cathode, as depicted in Figure 35-5-7.

DEFLECTION

The deflection module consists of the vertical and horizontal deflection modules, which recieve their respective vertical and horizontal sync pulses from the video and sync input model.

The vertical deflection module provides vertical sweep, hold, and height control for driving the vertical winding of the deflection yoke. In addition, this module provides for vertical blanking during retrace periods to prevent the flyback retrace lines from appearing on the picture tube. This blanking is accomplished by negative pulses provided to a control grid through use of the horizontal deflection module.

The horizontal deflection module provides horizontal sweep, hold, and width control by driving the horizontal winding of the deflection yoke in conjunction with the high-voltage module. This module also provides brightness, focus, and screen adjustment (regulation) – all of which are accomplished by driving the associated control grids G_1, G_2, and G_3, as indicated in Figure 35-5-7.

HIGH VOLTAGE

The high-voltage module supplies the required high voltage to the picture tube and, as mentioned previously, works in conjunction with the horizontal deflection module.

POWER SUPPLY

The power supply converts a.c. line voltage to low d.c. voltage for use by the video and deflection modules and is transformed to a higher level by the high-voltage module for use on the picture tube. The power supply also contains the typical regulation and protection necessary during operation.

APPLICATION

The most obvious use of video CRT systems is in television. With incorporation of a receiver and proper interfacing, the video CRT system could be utilized for this purpose. However, the process industry employs this system for other purposes, such as surveillance in security applications, monitoring of plant processes, and human communication with computers.

Nuclear power plants are required to maintain extensive security systems that encompass more than just the stationing of security guards at the plant gate. Such systems consist of a computer-based video and motion detector system. Video cameras are located throughout the plant property for close surveillance of areas selected to be displayed on video CRT systems.

Another use of this system is in the monitoring of actual fuel assembly removal and insertion from, and into, the reactor core at nuclear power plants. This display, with the use of strategically-located cameras, aids the operator during refueling operations by providing the visual aid necessary in fuel assembly movement. This system also is used to monitor boiler fires in gas- and oil-fired power plants and other processes in the chemical and oil industries.

Finally, this system is used on the digital CRT system previously described. With proper interfacing, the video system will display alphanumeric data required for communication with a computer. Computer data is supplied to a display generator that converts digitally coded data into a dot matrix field pattern for display compatability. The digital matrix patterns then are converted into composite video signals for input into the video and sync input section.

GRAPHICAL CRT SYSTEMS

Graphical CRT systems are used to display –

- Engineering data in graphical form.
- Controller or secured areas or rooms in graphical form for surveillance purposes.
- Plant process systems in diagrammical form to aid the operator in system operation.

Alphanumeric characters also are displayed to provide further descriptions and information.

Color graphical CRT systems, known as "color graphics," enhance displayed information.

CRT COLOR MONITOR

The CRT color monitor employed in graphical displays uses basic principles of television receiver design as described for video CRT systems. However, for the monitor to provide a high resolution color display, the following are required: (1) additional separate video inputs for the distinct colors, (2) a high-resolution shadow mask CRT, and (3) precision convergence. Therefore, additional separate cathodes for each color video input signal selected and a convergence are utilized to provide this resolution.

Typically, three video signals represent the three distinct colors — red, green, and blue. As indicated by Figure 35-5-7, this would require three video input and output amplifiers feeding their respective cathodes. When each cathode (or color gun) electron beam separately strikes the fact of the. tube, an illuminated color square, in the color associated with that cathode or gun, is produced. The firing of any combination of electron beams in the same time interval can create other colors such as yellow, violet, and white. The color illuminated on the display are produced by the discrete intensities of the electron beams striking the high-resolution color screen.

Converegence is utilized to support the high-resolution capabilities of the CRT. Convergence coils are provided for each cathode color beam prior to divergence, to provide the fine spacing required of each beam. The three convergence coils that make up the convergence yoke are driven by the horizontal and vertical deflection modules.

Graphical displays require a different raster configuration from that utilized by digital CRT systems; however, all supporting modules, such as the display control interface, and power supply, as similar in function.

The graphics display raster typically consists of 336 horizontal and 504 vertical lines. The raster provides a 7 x 7- or 7 x 14-character matrix, corresponding to normal or large-character configurations, respectively. Each character is displayed by an element or block matrix rather than by the dot matrix typical of a digital display. (See Figures 35-5-8 through 3-5-10.) In graphical or diagram displays (non-alphanumeric characters), any one or a combination of elements within the 7 x 7 matrix is used to configure the display desired.

DISPLAY GENERATOR

The display generator functions in the same manner as does the display control of the digital CRT system. Alphanumeric characters — normal, large, lower, and upper cases — are stored in main memory. Digital CRT systems typically display normal characters only.

Coded symbols and segments used to build graphical and diagrammical displays also are stored in main memory. Figures 35-5-11 and 35-5-12 illustrate a typical set of symbols used to build process-system diagrams for a nuclear power plant.

Command, editing, and control functions, as well as interface with the transmitter/receiver and keyboard module, are similar to the digital CRT systems.

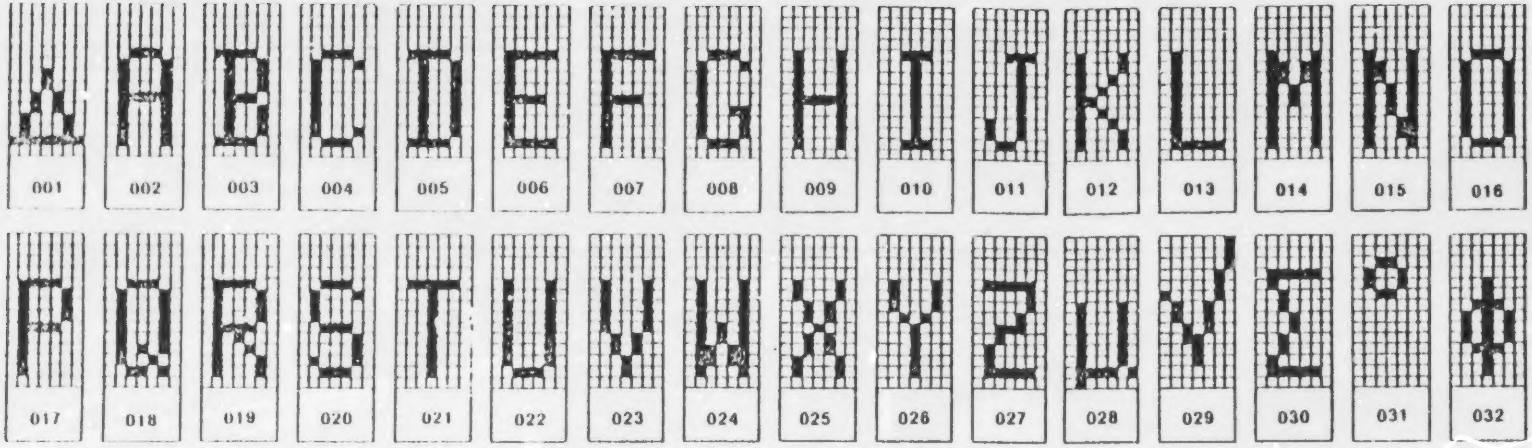

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Figure 35-5-8. Large letters.

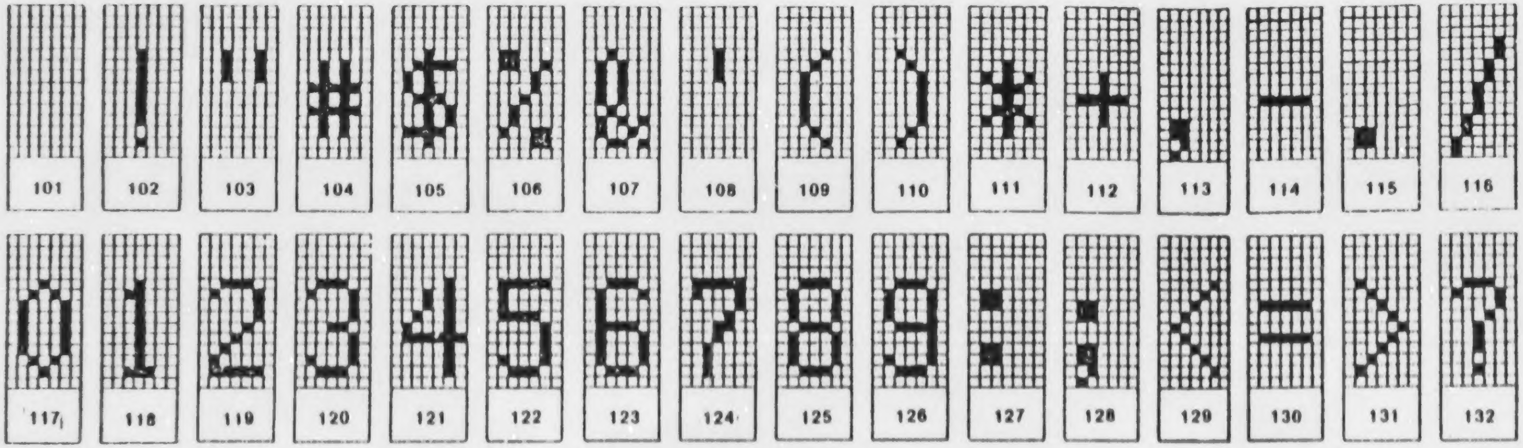
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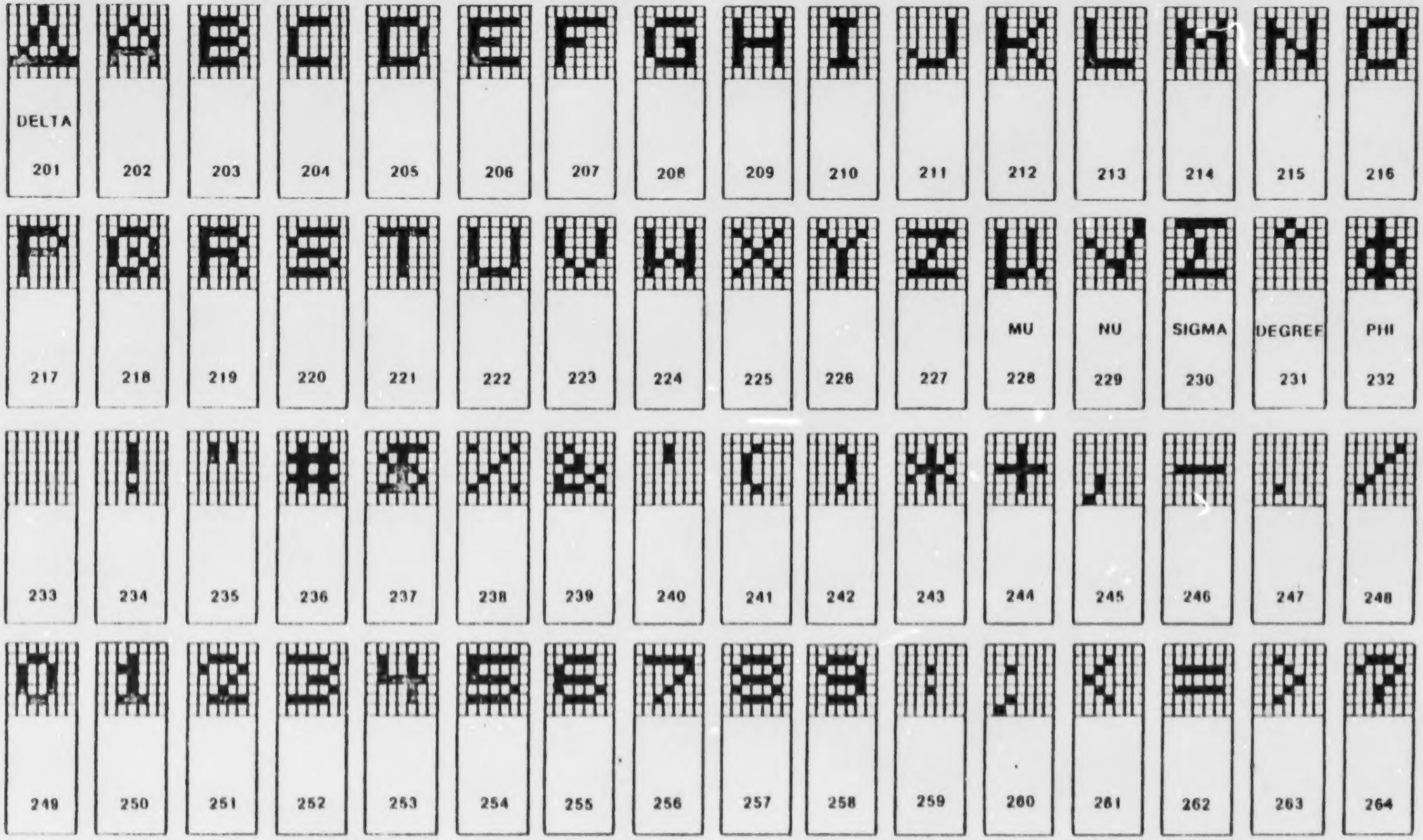
Figure 35-5-9. Large numbers and punctuation.


DELTA
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MU
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NU
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SIGMA
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DEGREE
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PHI
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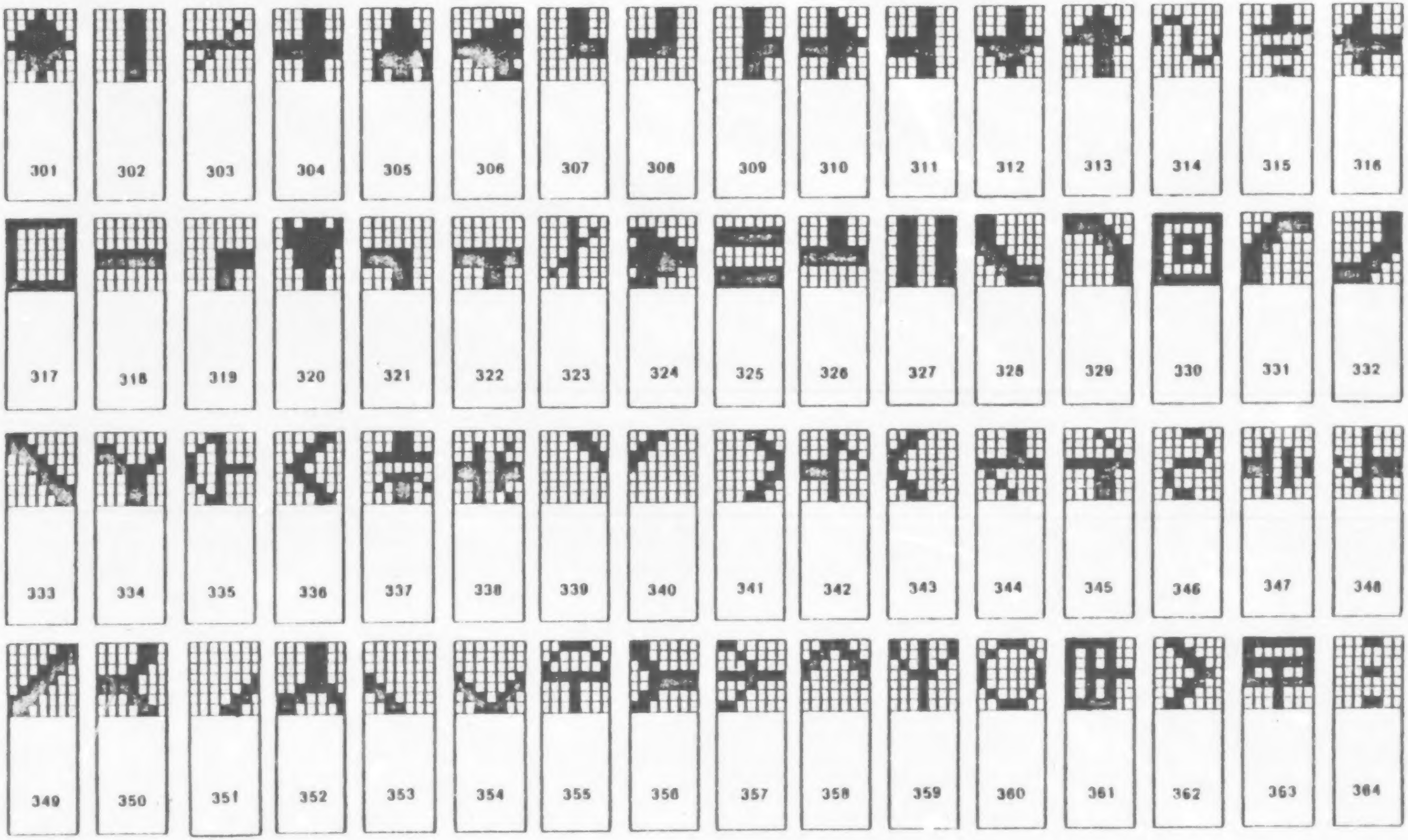
Figure 35-5-10. Normal alphanumeric characters.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352
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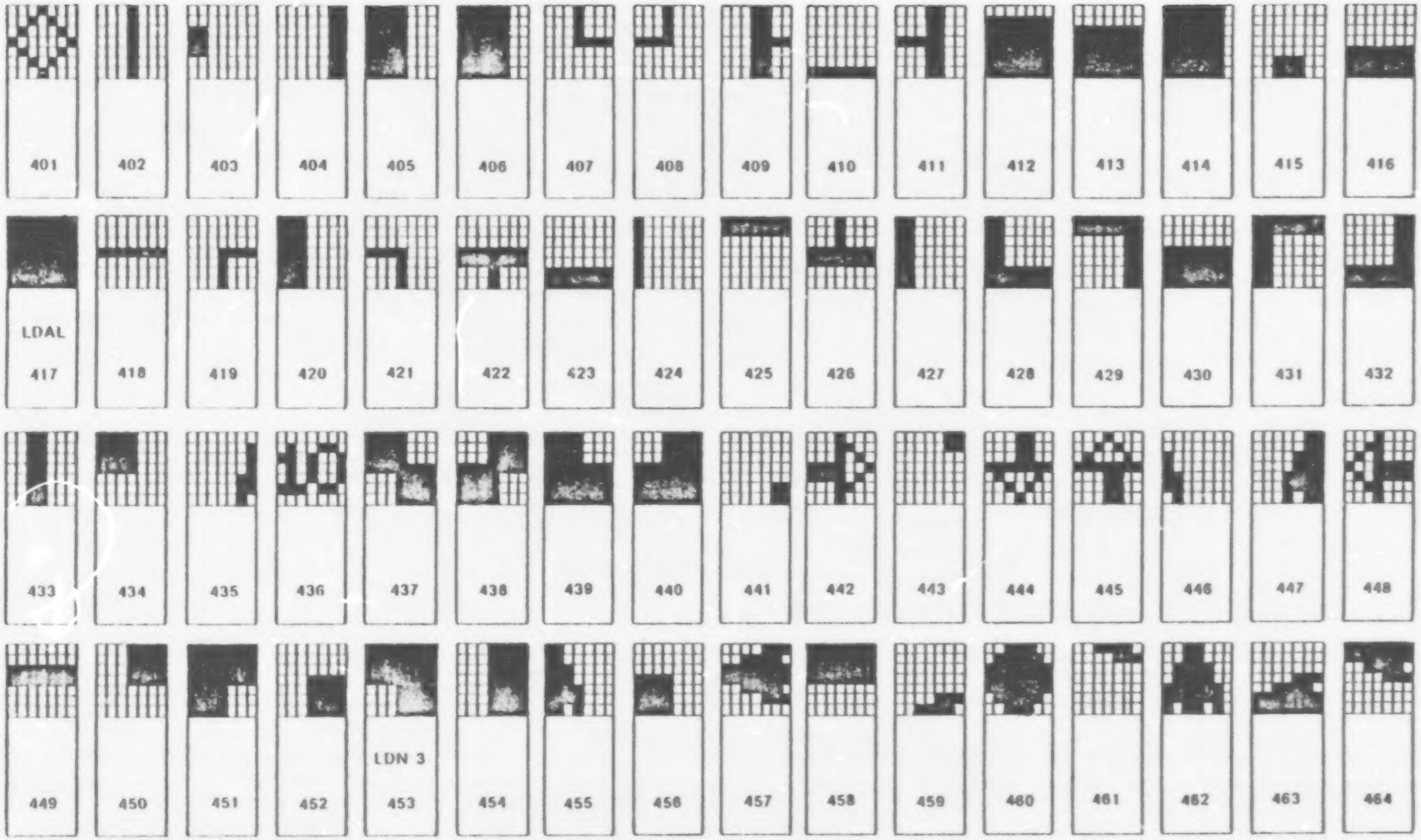
359
360
361
362
363
364

Figure 35-5-11. Normal symbols.


401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
LDAL
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
LDN 3
453
454
455
456
457
458
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461
462
463
464

Figure 35-5-12. Large symbols.

INTERFACE

The interface consists of a transmitter/receiver and a keyboard, as mentioned previously. However, keyboard functions are different from those provided by digital CRT systems. Figures 35-5-13 and 35-5-14 illustrate the functions provided for a typical nuclear power plant application. Most functions are self-explanatory; however, a few will be discussed here.

Normal characters and all other symbols in Figure 35-5-13 are available for selection when the LARGE/NORMAL character button is not depressed. Large characters and all other symbols in Figure 35-5-14 are available for selection when the LARGE/NORMAL character button is depressed. Eight colors can be selected by the corresponding button; and, in addition, process system diagrams are selectable, as illustrated, by the six buttons in the top portion of the keyboard. If button #2, REACTR COOLNT, were to be depressed, a diagram of the reactor coolant system with some operating parameters would be displayed as in Figure 35-5-15. In this diagram, the reactor is purple; the reactor coolant pumps (RCP) are yellow, and the steam generators (SG) are orange.

Positioning of the cursor also provides additional capabilities. For example, if further information on RCP 1 were desired, a more detailed diagram of RCP 1 with additional operating parameters would be displayed by positioning of the cursor underneath RCP 1 (Figure 35-5-15) and by depressing the DIAGRM button. If it were desired to have RCP 1 blink on and off at an alarm point, the SET/OFF ALARM button would have to be depressed to set the alarm point of the operating parameter. Then the cursor would be positioned underneath RCP 1, and the ON/OFF BLINK button would be depressed to achieve the desired display.

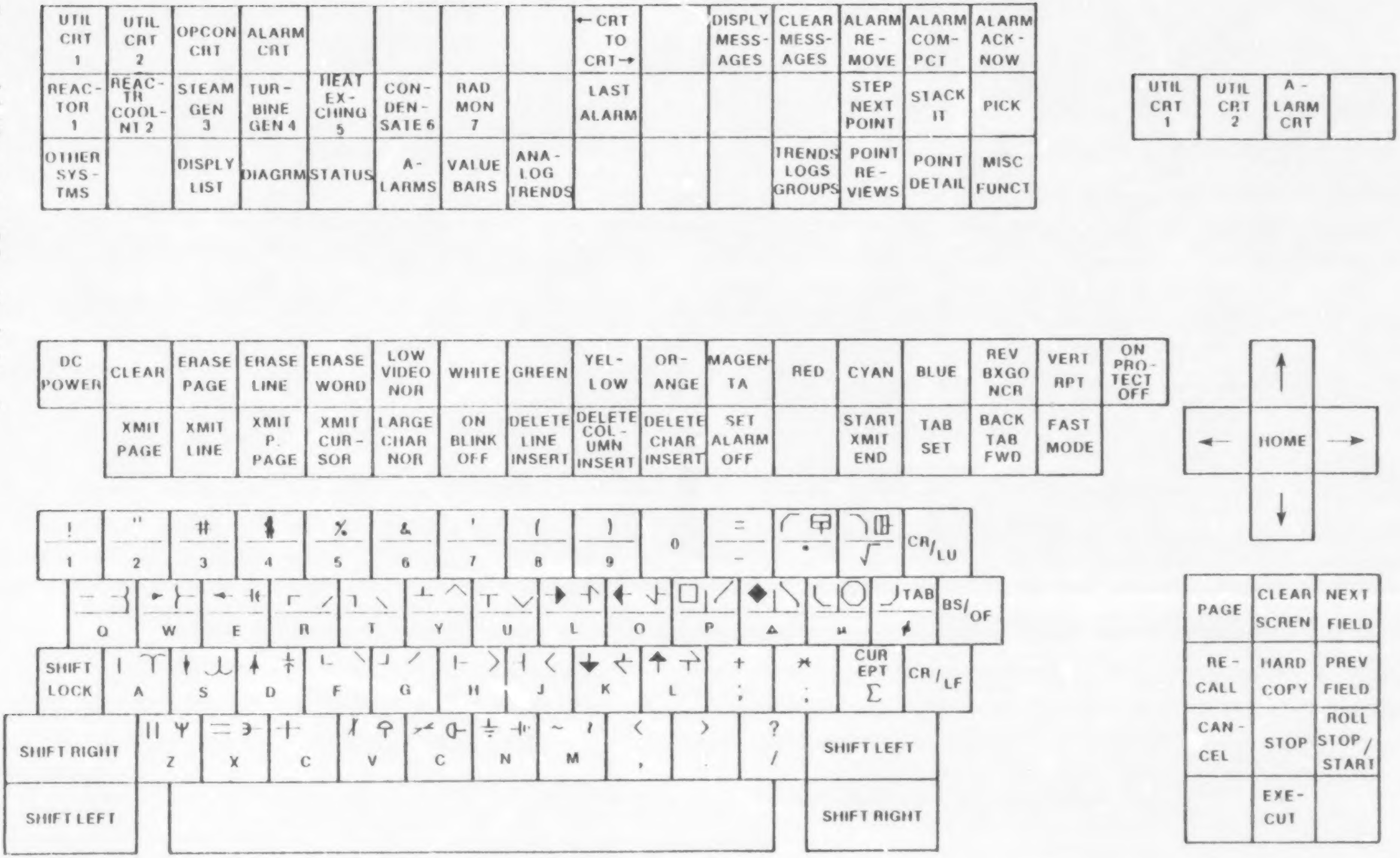

UTIL CRT 1
UTIL CRT 2
OPCON CRT
ALARM CRT
← CRT TO CRT →
DISPLY MESS-AGES
CLEAR MESS-AGES
ALARM RE-MOVE
ALARM COM-PCT
ALARM ACK-NOW
REAC-TOR 1
REAC-TR COOL-NT 2
STEAM GEN 3
TUR-BINE GEN 4
HEAT EX-CHING 5
CON-DEN-SATE 6
RAD MON 7
LAST ALARM
STEP NEXT POINT
STACK IT
PICK
OTHER SYS-TMS
DISPLY LIST
DIAGRM
STATUS
A-LARMS
VALUE BARS
ANA-LOG TRENDS
TRENDS LOGS GROUPS
POINT RE-VIEWS
POINT DETAIL
MISC FUNCT
UTIL CRT 1
UTIL CRT 2
A-LARM CRT
DC POWER
CLEAR
ERASE PAGE
ERASE LINE
ERASE WORD
LOW VIDEO NOR
WHITE
GREEN
YEL-LOW
OR-ANGE
MAGEN-TA
RED
CYAN
BLUE
REV BXGO NCR
VERT RPT
ON PRO-TECT OFF
XMIT PAGE
XMIT LINE
XMIT P. PAGE
XMIT CUR-SOR
LARGE CHAR NOR
ON BLINK OFF
DELETE LINE INSERT
DELETE COL-UMN INSERT
DELETE CHAR INSERT
SET ALARM OFF
START XMIT END
TAB SET
BACK TAB FWD
FAST MODE
↑
←
HOME
→
↓
! 1
" 2
# 3
$ 4
% 5
& 6
' 7
(8
) 9
0
= –
√
CR/LU
Q
W
E
R
T
Y
U
I
O
P
TAB
BS/OF
SHIFT LOCK
A
S
D
F
G
H
J
K
L
+ ;
* :
CUR EPT Σ
CR/LF
SHIFT RIGHT
Z
X
C
V
C
N
~ M
< ,
> .
? /
SHIFT LEFT
SHIFT LEFT
SHIFT RIGHT
PAGE
CLEAR SCREN
NEXT FIELD
RE-CALL
HARD COPY
PREV FIELD
CAN-CEL
STOP
ROLL STOP/START
EXE-CUT

Figure 35-5-13. Keyboard layout – normal characters.

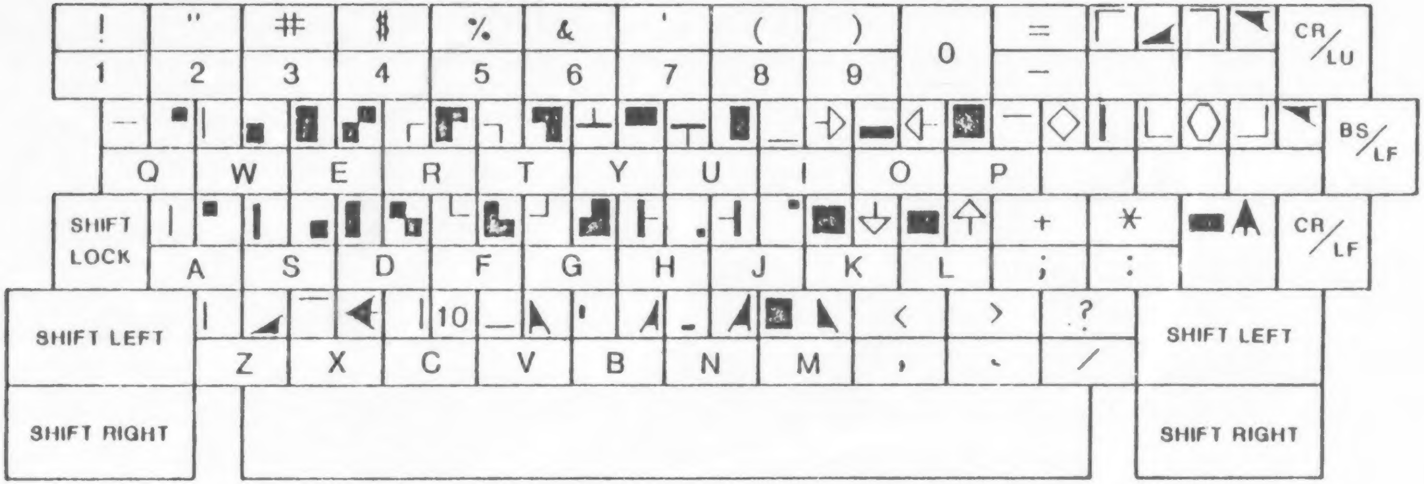

! 1
" 2
# 3
$ 4
% 5
& 6
' 7
(8
) 9
0
= –
CR/LU
Q
W
E
R
T
Y
U
I
O
P
BS/LF
SHIFT LOCK
A
S
D
F
G
H
J
K
L
+ ;
* :
CR/LF
SHIFT LEFT
10
Z
X
C
V
B
N
M
< ,
> .
? /
SHIFT LEFT
SHIFT RIGHT
SHIFT RIGHT

Figure 35-5-14. Keyboard layout – large characters.

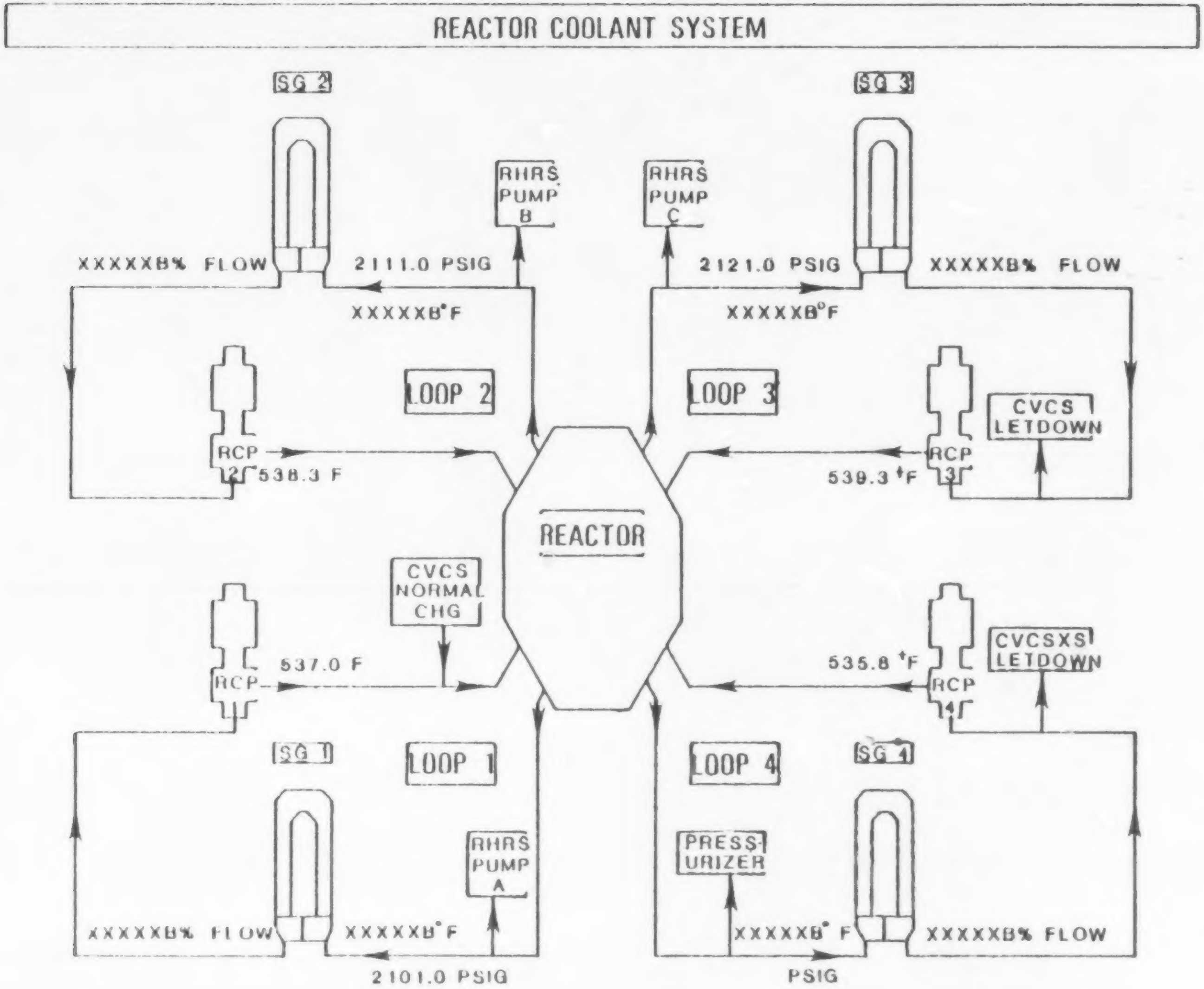

REACTOR COOLANT SYSTEM
SG 2
SG 3
RHRS PUMP B
RHRS PUMP C
XXXXXB% FLOW
2111.0 PSIG
2121.0 PSIG
XXXXXB% FLOW
XXXXXB°F
XXXXXB°F
LOOP 2
LOOP 3
CVCS LETDOWN
RCP 2
538.3 F
RCP 3
539.3 °F
REACTOR
CVCS NORMAL CHG
537.0 F
RCP
535.8 °F
CVCSXS LETDOWN
RCP 4
SG 1
LOOP 1
LOOP 4
SG 4
RHRS PUMP A
PRESSURIZER
XXXXXB% FLOW
XXXXXB°F
XXXXXB° F
XXXXXB% FLOW
2101.0 PSIG
PSIG

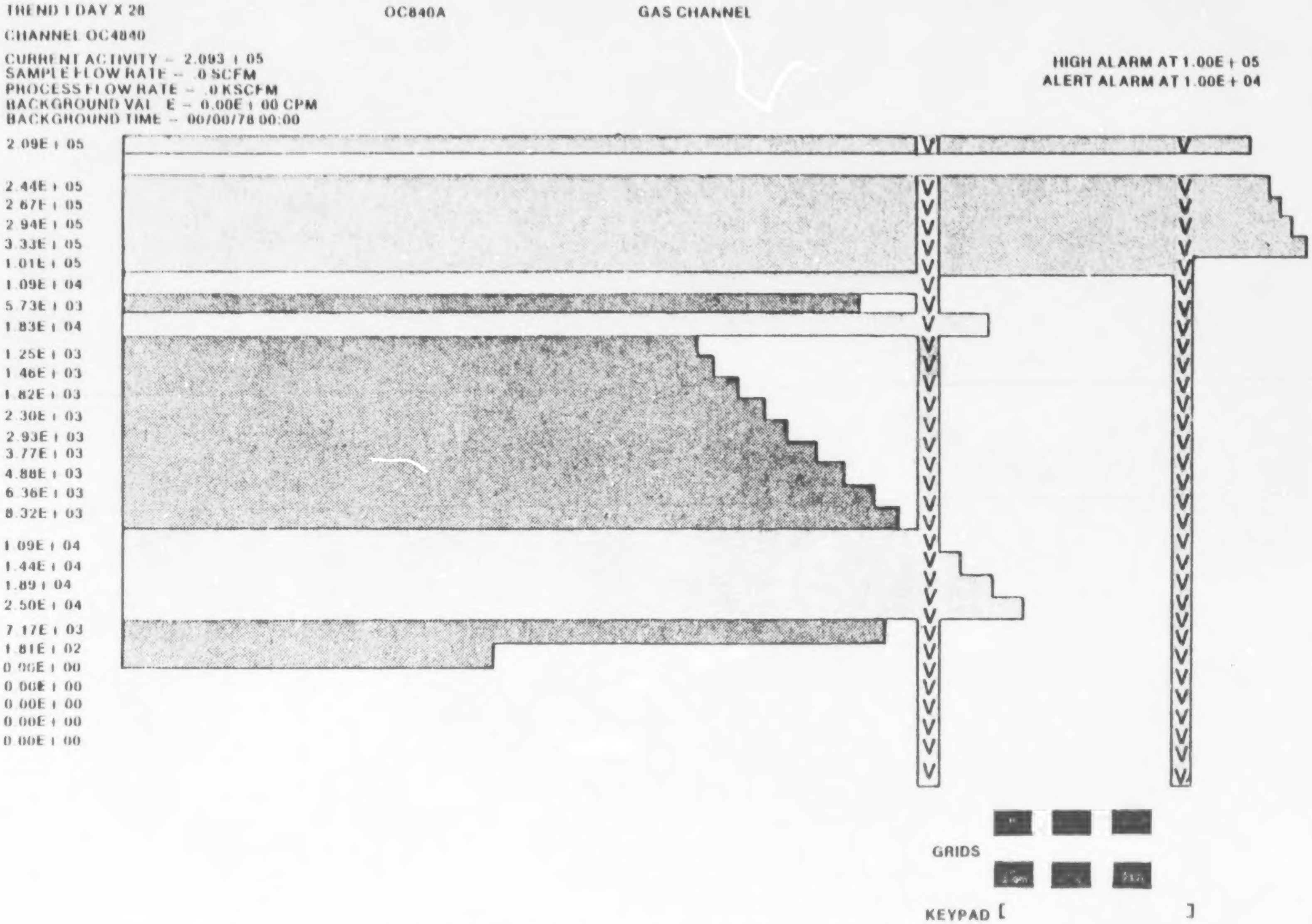
Figure 35-5-15. Diagram of reactor coolant system.

In some applications, a light pen (an external device that detects a particular light when placed against the picture tube) is utilized to achieve the same functions as the cursor. Both cursor and light pen also are used to control equipment, such as control valves and motor breakers, by a similar procedure.

APPLICATION

Modern nuclear power plants utilize graphical CRT systems in the applications listed previously at the beginning of this section. Figure 35-5-15 illustrated an example of the use of color graphics to display a plant process system for operator aid. In addition, operation or performance data or individual pieces of equipment also can be displayed in the form of bar charts or curves for engineering evaluation. This form of display also is used by other systems, such as the radiation monitoring system, to provide trend data of radiation levels monitored throughout the plant over a definite time interval. Figure 35-5-16 provides an example of such a display.

Displays that show two-dimensional layouts of plant areas or rooms are utilized by security systems as well as radiation monitoring systems. This display provides the security guard with the visual capability of monitoring personnel traffic or intrusions within controlled or secured areas. In addition, such displays aid the radiation protection technician in the monitoring of radiation levels throughout controlled areas of the plant by displaying radiation readings measured by individual monitors in the area selected. Figure 35-5-17 illustrates such a display.



TREND 1 DAY X 28

CHANNEL OC4840

CURRENT ACTIVITY – 2.093 + 05
SAMPLE FLOW RATE – .0 SCFM
PROCESS FLOW RATE – .0 KSCFM
BACKGROUND VALUE – 0.00E + 00 CPM
BACKGROUND TIME – 00/00/78 00:00

HIGH ALARM AT 1.00E + 05
ALERT ALARM AT 1.00E + 04

KEYPAD [ ]

OC840A
GAS CHANNEL
2.09E + 05
2.44E + 05
2.67E + 05
2.94E + 05
3.33E + 05
1.01E + 05
1.09E + 04
5.73E + 03
1.83E + 04
1.25E + 03
1.46E + 03
1.82E + 03
2.30E + 03
2.93E + 03
3.77E + 03
4.88E + 03
6.36E + 03
8.32E + 03
1.09E + 04
1.44E + 04
1.89 + 04
2.50E + 04
7.17E + 03
1.81E + 02
0.00E + 00
0.00E + 00
0.00E + 00
0.00E + 00
0.00E + 00
GRIDS

Figure 35-5-16. Graphical display of radiation-monitoring system.

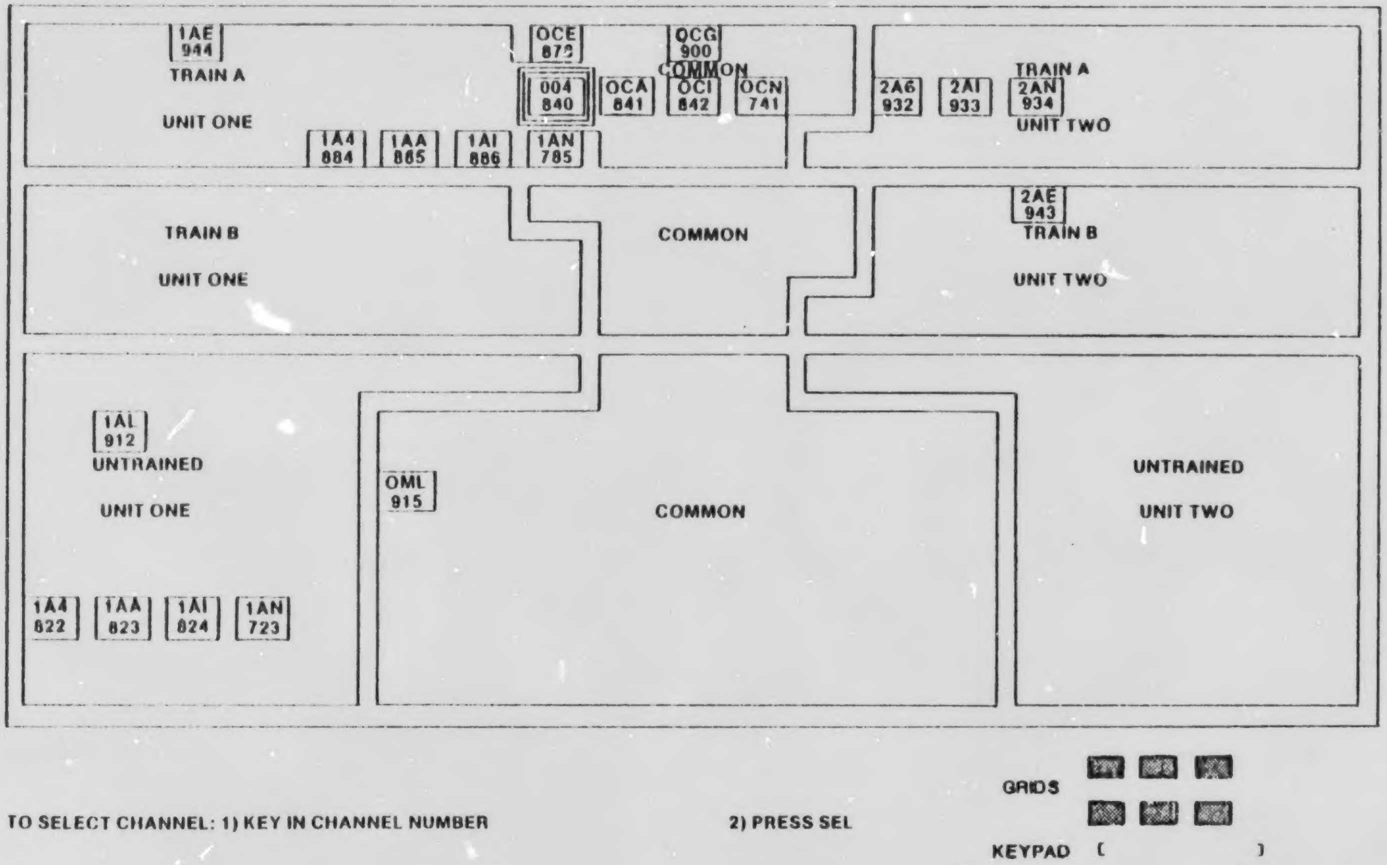

1AE
944
TRAIN A
UNIT ONE
1A4
884
1AA
885
1AI
886
1AN
785
OCE
872
004
840
OCA
841
OCG
900
COMMON
OCI
842
OCN
741
2A6
932
2AI
933
TRAIN A
2AN
934
UNIT TWO
TRAIN B
UNIT ONE
COMMON
2AE
943
TRAIN B
UNIT TWO
1AL
912
UNTRAINED
UNIT ONE
1A4
822
1AA
823
1AI
824
1AN
723
OML
915
COMMON
UNTRAINED
UNIT TWO
GRIDS
TO SELECT CHANNEL: 1) KEY IN CHANNEL NUMBER
2) PRESS SEL
KEYPAD [ ]

Figure 35-5-17. Graphical display of two-dimensional layout.

ADVANTAGES AND DISADVANTAGES OF CRT SYSTEMS

Several methods are employed to display information concerning plant conditions, whether the position is a process system, a secured area, or a radiation zone. Typically, this kind of information is displayed by readout devices such as dial indicators, recorders, alarm systems (annunciators), and local readout instruments. However, this information can be provided in one location by one device — the CRT system. When the CRT system is interfaced with a computer system, access to most information concerning plant conditions is provided on request.

Conventional means may be inconvenient, especially when readout displays are remote from the operating location. The location of readout devices in one local panel is an expensive undertaking due to the backing, space, and panel fabrication involved. However, it is not good practice to depend upon one system, such as the CRT system, to provide all plant operting information. Failure of such a system would render the plant data unavailable.

Due to its interface with computer systems, the CRT system provides information beyond plant operating values. Engineering calculations on system performance, historical data, accumulated radiation dosage of personnel, and other data is stored in computer systems and displayed on CRT systems on request. This interface with the computer makes the CRT system a more versatile system than the readout devices discussed previously. In addition, CRT systems display much more accurate data than can be read from readout devices.

Since there are less moving parts in CRT systems, there is correspondingly less alignment, adjustment, or repair.

However, due to the sophistication involved, more intensive training is required of personnel to maintain and operate these systems than required for conventional devices.

EXERCISES

1. Describe the function of the major CRT components:
   A. Components of digital CRT systems.
      1. Video monitor.
      2. Display control.
      3. Interface.
      4. Power supply.
   B. Components of video CRT systems.
      1. Video and sync input.
      2. Video output.
      3. Video deflection.
      4. High-voltage module.
      5. Power supply.
   C. Components of graphical CRT systems.
      1. Color monitor.
      2. Display generator.
      3. Interface.
2. Write a short paper, of at least one page, on the importance of CRT systems.

MATERIALS

Tracing paper, 8½ x 11" - one sheet for each student. (As a substitute, onionskin typing paper may be used.)
Drafting tape.

PROCEDURES

FIELD TRIP TO A NUCLEAR POWER PLANT

1. Arrange to visit at least one nuclear power plant and to tour the control room. Locate all CRT displays.
2. Identify the CRT systems; describe their capability.
3. If possible, discuss with operation and maintenance personnel the advantages and disadvantages of the CRT systems being utilized, and list each point for further evaluation.

CRT DISPLAY OF OPERATING CONDITIONS

The purpose of this procedure is to illustrate how each CRT system could display the operating condition for the system illustrated in Figure 33-5-18. This system is a chemical and volume control one and is associated with the reactor coolant system illustrated in Figure 33-5-15. This procedure should be performed by each student separately.

1. With a small strip of drafting tape, attach a piece of tracing paper or onionskin paper over Figure 33-5-18. The paper serves as an overlay on which to write.
2. Draw on the overlay the segments used to develop the displayed items for the system in Figure 33-5-18.

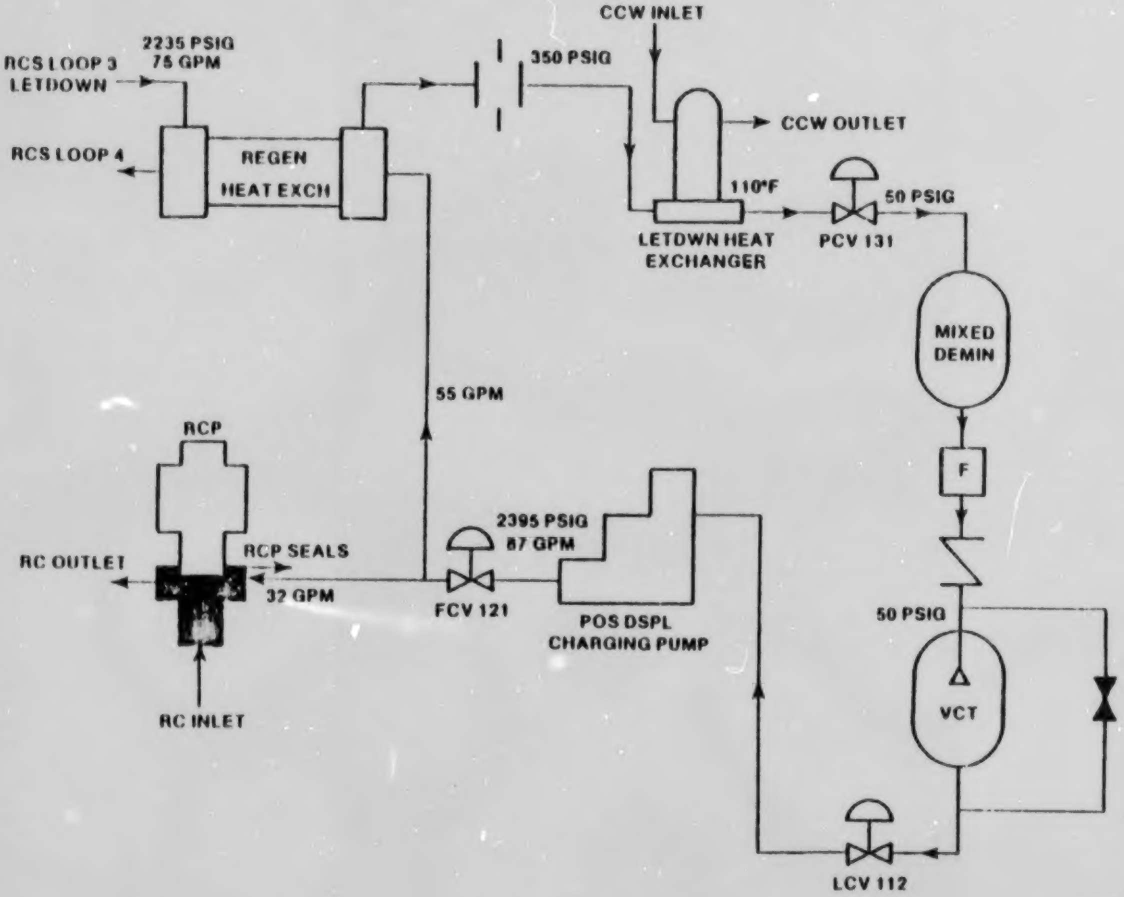

CCW INLET
2235 PSIG
75 GPM
RCS LOOP 3 LETDOWN
350 PSIG
CCW OUTLET
RCS LOOP 4
REGEN HEAT EXCH
110°F
50 PSIG
LETDOWN HEAT EXCHANGER
PCV 131
MIXED DEMIN
55 GPM
RCP
F
2395 PSIG
87 GPM
RC OUTLET
RCP SEALS
32 GPM
FCV 121
50 PSIG
POS DSPL CHARGING PUMP
VCT
RC INLET
LCV 112

Figure 35-5-18. Chemical and volume control system.

Use the coded symbols contained in Figures 35-5-8 through 35-5-12.

DATA TABLES

None.

REFERENCE MATERIALS

Aydin Controls. *Operation and Maintenance Manual, 8025 High Resolution 19-inch Diagonal Color Monitor*. Document No. 150-7030-001. Fort Washington, PA: Aydin Controls, 1978.

Operation and Maintenance Manual for Model 5215 Display Generator, Vol. 1. Document No. 150-6040-001A. Fort Washington, PA: Aydin Controls, 1977.

Courac. *Installation, Operation and Maintenance Manual – SNA Series Video Monitors*. Covina, CA: Courac Corporation.

Data General. *Technical Manual - DGC Display 6012*. Rev. 00. Southboro, MA: Data General Corporation, 1976.

TEST

1. Define the following terms:
   a. CRT.
   b. Electron gun.
   c. Anode.
   d. Alphanumeric characters.
   e. Raster.
   f. Keyboard.
   g. Composite video signal.
   h. Noncomposite video signal.

i. Deflection.

j. Color graphics.

k. Convergence.

l. Cursor.

m. Coded symbols.

n. Digital display.

2. Functionally describe, with the aid of block diagrams, the following three CRT systems:
   a. Digital systems.

b. Video systems.

c. Graphical systems.

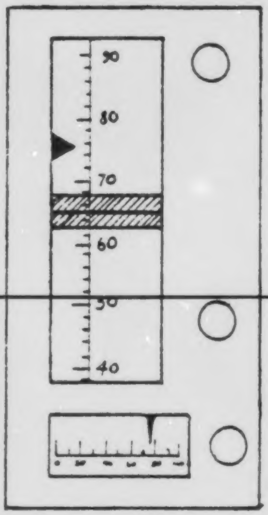
3. List the advantages and disadvantages of CRT systems over conventional means.

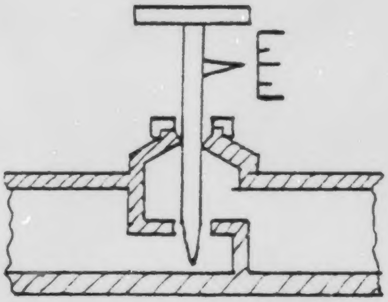
4. List applications of each type of CRT system.

NUCLEAR TECHNOLOGY

MODULE 35-6

PREVENTIVE MAINTENANCE FOR SYSTEMS AND COMPONENTS





SYSTEMS AND COMPONENTS

COURSE 35

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

CONTENTS

COURSE 35 SYSTEMS AND COMPONENTS

MODULE 35-1	Electrical Distribution
MODULE 35-2	Instrumentation and Control for Major Plant Components
MODULE 35-3	Recording and Display Devices
MODULE 35-4	Process Control Loops and Devices
MODULE 35-5	Cathode-Ray Tube Systems (CRT)
⇨ MODULE 35-6	Preventive Maintenance for Systems and Components
MODULE 35-7	Instrument Reliability

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INTRODUCTION

Preventive maintenance is the practice of inspection, testing, and reconditioning a system at regular intervals in order to prevent equipment failures, when possible, and to reduce operating costs. If a nuclear power plant is shut down for only a few hours, the cost to the power company may be several hundred-thousand dollars. In a nuclear power plant, strong emphasis is placed upon nuclear safety, industry standards, regulatory guides, and technical specifications.

Computers provide much data for a preventive maintenance system. They keep track of such things as –

- Due dates for inspection, maintenance, and calibration.
- Parts used in maintenance.
- Equipment location.
- Maintenance history.
- Radiation dosage.

This module defines and discusses the fundamentals of preventive maintenance and other related activities and explains the methods utilized to enhance the availability and reliability of instrument and control equipment and systems.

MODULE PREREQUISITES

The student should have completed Course 3, "Principles of Process Instrumentation," and Module 35-1, "Electrical Distribution."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
    - Maintenance.
    - Preventive maintenance.
    - Corrective maintenance.
    - Overhaul maintenance.
    - Calibration.
    - Surveillance test.
2. Describe general maintenance inspection procedures, purpose, and safety aspects.
3. List the elements of documentation and scheduling methods used in preventive maintenance.
4. Explain the purpose of planning, equipment or system clearances, and information or data recording in a preventive maintenance system.
5. Explain how quality control interfaces with an effective preventive maintenance system.
6. Using general guidelines and manufacturer's recommendations, prepare a simple preventive maintenance schedule; and write procedures for assigned instrument or control equipment.

DEFINITIONS

MAINTENANCE

Maintenance - visual examination for worn components or loose connections, replacement of broken or worn parts, repair and modification of equipment; encompasses preventive, corrective, and overhaul maintenance.

PREVENTIVE MAINTENANCE (PM)

Preventive maintenance (PM) - checking, adjustment, routine replacement, lubrication, or cleanup necessary to maintain equipment in operating condition. PM is performed on a scheduled basis.

CORRECTIVE MAINTENANCE (CM)

Corrective maintenance (CM) - replacement of broken parts and repair of components to place equipment back into an operating condition. CM is performed on an unscheduled basis.

OVERHAUL MAINTENANCE (OM)

Overhaul maintenance (OM) - examination, replacement, reconditioning, reassembly, and testing of components and equipment. OM is performed on a planned, scheduled basis.

CALIBRATION

Calibration – comparison of instrument or control equipment to measuring and test equipment or reference standards of greater accuracies to detect, quantify, and report or eliminate those inaccuracies in instrument or control equipment.

SURVEILLANCE TEST

Surveillance test – testing of components of equipment to ensure that failures or substandard performance do not remain undetected and that reliability is maintained. Surveillance testing is performed on a periodic, scheduled basis on safety-related equipment used at nuclear power plants.

FUNDAMENTALS OF PREVENTIVE MAINTENANCE

The basic purpose of preventive maintenance (PM) is (1) to reduce maintenance costs and (2) to maintain or improve reliability. To support the purpose of PM, performance criteria are developed for the proper design or utilization and construction or installation of equipment. During operation, PM can take the form of an extensive and documented periodic task or exist simply as a lubrication or an inspection of components, equipment, or systems on a periodic basis.

Factors that contribute to the extent of a PM program are –

- Cost of the program compared to the reduction of repair costs and improvement on equipment performance.
- Percent utilization of equipment.

In the nuclear power industry, two other factors are considered –

- Nuclear safety-related application.
- Industry standards, regulatory guidelines, and technical specifications.

An efficient PM program is developed, however, by the integration of other functions, such as a well-documented system, work planning and scheduling, training, work measurement, controlled reports, and adequate tools. (For a discussion of manual PM documentation, refer to the works in the Reference Materials section.)

With instrument and control equipment, calibration is considered to be part of PM when performed on a planned, periodic basis since it meets the basic purposes of PM mentioned previously. In addition, periodic calibration of safety-related instrument and control equipment is a requirement under the plant technical specifications.

SAFETY PRECAUTIONS

When performing PM or any other maintenance work, standard safety precautionary measures are observed. These measures may involve the verification of energized or de-energized circuits; eye, ear and hearing protection; and proper protection against potentially dangerous equipment such as high-pressure air, gas, or steam sources. These precautionary measures are stressed in safety and training programs and are incorporated in safety manuals and in PM procedures as precautionary notes.

Equipment or system clearances, which consist of the removal from service of equipment or systems and the tagging of each for the specific maintenance required, provides additional protection against potentially dangerous conditions.

In instrument or control maintenance, precautionary measures mainly consist of those mentioned above.

In the nuclear power industry, additional safety measures concerning radiation protection must be observed. These measures include clothing, air-packs, gloves, and boots to protect against airborne and liquid particulate contamination and radiation. In addition, time is an important aspect dependent upon the amount of radiation existent in the work area.

The health physicists at nuclear power plants issue radiation work permits (RWP) to ensure that personnel understand and take precautionary measures prior to entering or working in radioactive areas and handling contaminated equipment, liquids, or gases. Again, PM procedures contain precautionary notes for working with contaminated materials or in radioactive areas and specify RWPs when required by the health physicists.

MAINTENANCE PROCEDURES

Preventive maintenance procedures are as extensive and thorough as required by the overall PM program. Whether the program is a manual or a computer-based system, the work involved and the information or data gathered are dependent upon the intent of the program.

To illustrate these variances, Appendixes A, B, and C, respectively, contain the following PM procedures:

- 480-volt switchgear mechanical and electrical maintenance.
- Rod control system maintenance.
- Electropneumatic instrument and control equipment maintenance.

The 480-volt switchgear PM procedure is a basic inspection and cleaning procedure performed on equipment on an annual basis. Information or data required for development of the switchgear maintenance history file is minimum. In addition, this procedure has been developed for a manual PM program in which all information and data is manually recorded and placed in the history file. Manual periodic search of the records is required to determine when the PM procedure should be performed again.

The Rod Control System PM procedure is another basic inspection and cleaning procedure. This procedure applies to an instrumentation system and requires that all information, data, maintenance history, and scheduling be handled manually.

Instrument and control equipment requires more than the spection and cleaning to meet the intent of PM, although these certainly are incorporated into PM procedures. Additional maintenance requirements imposed would be the periodic calibration and testing of instrument and control equipment. With proper records developed for recording information and data, a history file of calibration and testing data for each piece of instrument and control equipment can be maintained. Through continued periodic analysis of the data, the following factors can be determined:

- Frequency of inspection and cleaning.
- Frequency of calibration and testing.
- Proper application.

- Component periodic replacements.
- Equipment or component modification.

Each of these factors makes a definite contribution to the prevention of equipment or system failures since instrument and control equipment provides direct and indirect control of each.

Instrument and control equipment can be placed into three categories: (1) pneumatic, (2) electropneumatic, and (3) electronic.

Pneumatic instrument or control equipment entails those that operate, indicate, and/or control utilizing medians such as air, gas, oil, or fluid to sense and transmit process signals. Typical equipment included in this category is listed in Table 35-6-1.

Electropneumatic instrument or control equipment converts pneumatic signals to electronic or electric signals, or vice-versa, for operation, indication, and/or control. This type of equipment is used mainly to interface with total electronic process control instrumentation systems and is listed in Table 35-6-1.

Electronic instrument or control equipment consists of equipment that operates, indicates, and/or controls, utilizing the conductivity of materials to sense and transmit process signals. The majority of such equipment is used in electronic process control instrumentation systems, although other items exist, as indicated by Table 35-6-1.

The PM procedure in Appendix C applies to electropneumatic instrument and control equipment as listed in Table 35-6-1. Basic inspection and cleaning instructions are incorporated; however, the bulk of maintenance performed is in accordance with equipment instruction manuals.

TABLE 35-6-1

INSTRUMENT & CONTROL EQUIPMENT

I. PNEUMATIC

A. Pressure gages
B. Flow gages
C. Level gages
D. P/DP transmitters
E. Filled temperature systems
F. Flow totalizers
G. Valve positioners
H. Pneumatic computing relays
I. Manual loading stations
J. Pneumatic M/A stations

II. ELECTROPNEUMATIC

A. Pressure switches
B. Flow switches
C. Level switches
D. Pressure-indicating switches
E. Flow-indicating switches
F. Level-indicating switches
G. Temperature-indicating switches
H. P/DP transmitters
I. Turbine meters
J. Anemometers
K. Wind vanes

III. ELECTRICAL

A. T/C, RTDs
B. Indicators
C. Modules, such as—
- Counters
- Convertors & isolators
- Summing amplifiers-auctioneers
- Analog computing relays
- Controllers
- Special modules

D. Recorders
E. Power supplies
F. Radiation monitors
G. Conductivity elements

The data sheet in Figure 35-6-3 requires that pertinent information about the instrument or control equipment, mea-uring and test equipment used, and calibration data be recorded.

Drift rates, which are used to determine replacement or modification of components or redesign of application, are determined by precalibration data obtained prior to performance of any maintenance. The pass/fail and component stock code/quantity spaces also provide additional clues to the proper design or application or failure rates of equipment or components.

This procedure is adapted to computer application through the use of the data sheet. The following information on the data sheet is stored in the computer in the equipment history file to monitor maintenance activities on each instrument or piece of control equipment and the components of which they consist:

- Tag no.
- Maint. proc. no.
- Date.
- Due date.
- Type (calibration/PM, CM).
- Frequency.
- Performing org.
- Pass/fail.
- Period hrs.
- M&TE tag nos.
- MAR no. (maint. action request).
- Remarks.
- Man mrem (radiation dosage).
- Manhours.
- Stock code/qty. (of equipment or components).

Each item listed is shaded on the data sheet. Not all items directly relate to PM, and calibration data is not stored because high drift rates or replacements are inferred by the date of calibration, pass/fail, and stock code/quantity information. Scheduling of PM is determined by the computer, utilizing the date of calibration and frequency.

SCHEDULING OF PREVENTIVE MAINTENANCE

BASIS

Preventive maintenance is performed periodically and is based upon two factors: (1) frequency determined for the particular instrument or control equipment and (2) out-of-service date and period scheduled.

The frequency determined for performing PM is based upon the manufacturer's recommendation, general guidelines, and accumulated maintenance history. Initial determination is based on recommendations outlined in maintenance instruction manuals; however, past knowledge of the performance of the equipment is an important factor, as well. Table 35-6-2 lists the recommended calibration frequencies of different types of equipment, based purely on past experience. The accumulated maintenance history then is used to re-evaluate frequencies established and to determine whether a change in frequency is required. It must be noted that PM frequencies can be decreased, based upon continued good inspections and stable performance of instrument and control equipment. With a decrease in frequency of performance of PM, maintenance costs decrease; equipment or system outages decrease, with a corresponding increase in availability and reliability; and plant production

TABLE 35-6-2

GENERAL GUIDELINES FOR DETERMINATION OF INSTRUMENT AND CONTROL EQUIPMENT CALIBRATION INTERVALS

Instrument Type	Safety-related	Nonsafety-related	Plant Effluent related
Indicators	2 yr	2 yr	1 yr
Comparators	2 yr	2 yr	1 yr
Switches	2 yr	2 yr	1 yr
Recorders	2 yr	2 yr	1 yr
Transmitters	2 yr	2 yr	1 yr
Integrators	2 yr	2 yr	1 yr
Controllers	2 yr	2 yr	1 yr
Analyzers	1 yr	1 yr	1 yr
Signal modifiers	2 yr	2 yr	1 yr
Gages		2 yr	1 yr

time increases. When a decrease in PM frequency occurs, it is analyzed as a verification that the design, construction, and installation of the component, equipment, or system meet the required application.

Although frequency of PM performance is established, the actual date and time scheduled for such maintenance depend upon plant priorities or other unrelated equipment or system outages. If equipment must be placed in an out-of-service condition during production time, the cost/benefit factor is analyzed closely; that is, the cost of placing equipment or systems in out-of-service condition may be greater to production than can be benefited by the maintenance. However, if production were to be reduced or shut down due to an unrelated equipment or system outage, PM could be scheduled only if its performance would not contribute to the time production in either mode. Therefore, the actual date for performance of PM depends upon plant conditions and the required time and is determined as the due date is approached.

COMPUTER APPLICATION

The primary functions for a computerized system are management and control of (1) PM, (2) surveillance test, (3) calibration, and (4) provision of a computerized component and equipment history. The following are some specific functions of a computerized system pertaining to PM:

- Identification of inspection, maintenance, or calibration due on instrument and control equipment within the same system (and/or requiring the same plant or system) condition. This function is useful for coordination of activities due to be performed in the same time frame or that require the same system or plant condition to perform them.
- Recording of parts used in performing maintenance on instrument and control equipment. This function is beneficial in planning of similar activities for the same equipment at a later date or for identifying and analyzing chronic problems with a single component or type of component.
- Identification of equipment location. This function aids in the rapid location of equipment by building, elevation, room, area, or panel number (if applicable).

- Availability of maintenance history for each instrument or piece of control equipment, either interactively from a computer terminal or in a printed format. This function replaces the manual means of obtaining equipment history and assists in identification and analysis of chronic equipment problems.
- Scheduling of maintenance or calibration activities.
- Tracking of radiation dosage when PM is performed in radioactive areas in a nuclear power plant. This function aids in determination of scheduling and manhour requirements to perform PM in these areas.

With use of the history file, the computer provides pertinent information and calculates the due date for the PM by applying the specified period to the date at which the maintenance was last performed. The history file consists of the data previously listed in the section on maintenance procedures and is obtained from a data sheet similar to that used in the electropneumatic instrument and control equipment PM procedure. Plant, system, or equipment conditions also are used by the computer to provide sufficient information to the user for performance of PM on a scheduled basis. A schedule summary printout such as that illustrated in Figure 35-6-1 aids in meeting this objective.

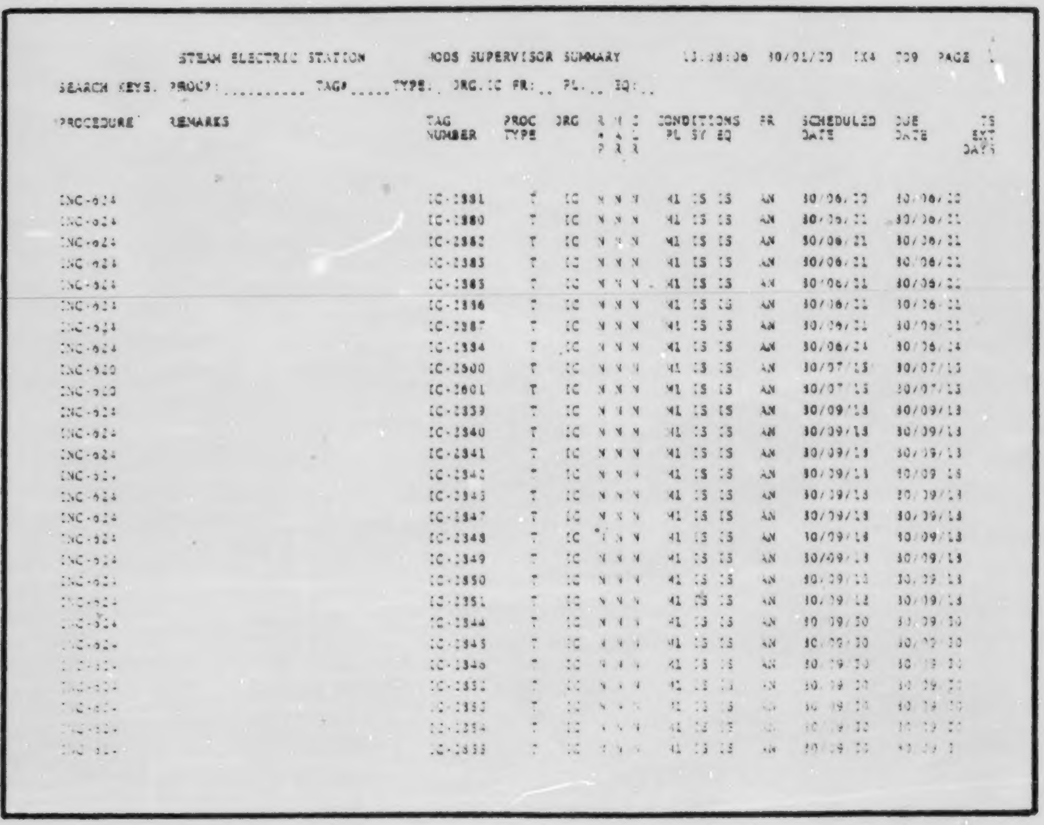


Figure 35-6-1. Schedule summary printout.

QUALITY CONTROL

Quality control was defined in Course 14, "Introduction to Quality Assurance/Quality Control," as "those actions taken by quality-control personnel (inspections, checks and other verifications) to ensure that work activities are performed in accordance with approved procedures. The purpose is to ensure that prescribed quality requirements are met."

A PM program developed on paper does not ensure increased equipment reliability or availability. The program is only as effective as adherence to it and the quality of work performed.

Quality control, therefore, interfaces with all phases of PM (e.g., design, construction/installation and performance) to ensure that PM is performed at prescribed intervals, with quality workmanship and all pertinent data or information recorded. This interfacing increases the likelihood of maintaining a cost-effective program and reliable/available equipment; systems; and, consequently, plant production.

EXERCISES

1. What are the basic differences between PM and OM (overhaul maintenance)?
2. Why can surveillance testing be considered part of PM? What is the main difference between them?
3. Explain how radiation affects the scheduling of PM on equipment in radioactive areas.
4. Explain the difference between frequency and scheduling.
5. Explain what cost factors are involved in performing PM.

MATERIALS

Electronic pressure transmitter.
Pneumatic control-valve positioner.
Recorder.

PROCEDURES

1. Prepare a PM schedule, using Data Table 35-6-1, and procedures for the following instrument and control equipment, referring to manufacturer's recommendation and the general calibration guidelines in Table 35-6-2:
    - Electronic pressure transmitter.
    - Pneumatic control-valve positioner.
    - Recorder.

2. Ensure that inspections, cleaning, replacement, calibrations, or other maintenance activities are included in the procedures.

DATA TABLE 35-6-1

PROC. NO.	DESCRIPTION	FREQ.	DATE LAST DONE	DATE DUE	DATE SCH.	DATE COMP.	CALIB. PASS/ FAIL	PERIOD HRS.	MANUFACTURER'S COMPONENT/PART NOS.	REMARKS

REFERENCE MATERIALS

Morrow, L.C., ed. *Maintenance Engineering Handbook*. 2nd ed. New York: McGraw-Hill Book Company, 1966.

TERA Corporation, *Comanche Peak Steam Electric Station Maintenance and Operations Data System (MODS) Users' Guide*. Berkeley: TERA Corporation, 1978.

APPENDIX A

480-VOLT SWITCHGEAR MECHANICAL AND ELECTRICAL MAINTENANCE

PURPOSE

1. To outline the annual maintenance and cleaning of 480-volt switchgear.

REFERENCES

1. ITE Instruction Manual #1B-9.1.7-6.
2. Westinghouse Manual M.8-3051, Inspection and Test of Electrical Equipment.

LIMITATIONS AND PRECAUTIONS

1. Primary and control power must be de-energized either under normal clearance procedures or with Shift Supervisor approval.

SPECIAL TOOLS AND EQUIPMENT

None.

TESTING AND ACCEPTANCE CRITERIA

1. Thorough cleanliness of breaker and cubicle.
2. All connections are properly tightened.
3. No damage to arc chutes.
4. Contacts shall be in good condition.
5. A minimum megger reading of 1 megohm at 1000 V d.c.
6. Mechanical adjustments shall be correct per manufacturer's instruction manual.
7. Electrical function test from Control Room.

PROCEDURE

1. Remove breaker per Procedure EM.101 for K600 and K1600 breakers, and Procedure EM.102 for K300 breakers.
2. Remove arc chutes, and inspect.
3. Check all electrical connections for tightness (including all terminal screws), and tighten if necessary on breaker and in the cubicle.
4. Check all mechanical connections for tightness, and tighten if necessary on breaker and in the cubicle.
5. Inspect contacts, and replace if needed.
6. Thoroughly clean breaker, using vacuum and lint-free cloth.
7. Clean cubicle.
8. Check all mechanical adjustments and readjust if needed, per vendor's instruction manual.
9. With breaker closed, megger at 1000 V d.c. phase-to-frame and phase-to-phase, and record in Figure 35-6-2 Data Sheet.

10. Reinstall breaker EM.101 for K600 and K1600 breakers and EM.102 for K3000 breakers and rack to test position.
11. Have Operations operate breaker from Control Room in test position.

ENCLOSURE

1. Data Sheet.

BREAKER NUMBER: ____________________

PERFORMED BY: ____________________ DATE: ____________________

	INITIAL:	DATE:
Arc chutes checked	________	________
Connections checked	________	________
Contacts checked	________	________
Breaker & cubicle cleaned	________	________
Mechanical adjustments checked	________	________
Megger readings	________	________

OA to frame	________
OB to frame	________
OC to frame	________
OA to OB	________
OA to OC	________
OB to Oc	________

Breaker operated in test position ________ ________

REVIEWED BY ____________________

DATE ____________________

Figure 35-6-2. Typical data sheet for 480-volt switchgear maintenance.

APPENDIX B

ROD CONTROL SYSTEM MAINTENANCE

PURPOSE

The purpose of this procedure is to isolate and prevent rod motion of one Power Cabinet for maintenance while the plant is at power.

REFERENCES

Westinghouse Full-Length Rod Control Technical Manual.

INITIAL CONDITIONS

A. The d.c. Hold Cabinet is energized.
B. The Power and Logic Cabinets are energized.

PRECAUTIONS

A. Take only one Power Cabinet out of service at a time.
B. Place only one group of rods on the d.c. Hold Bus at a time.
C. Ensure that no movement of the affected rod bank is attempted while a group of rods is on the d.c. Hold Bus. Have operations go to manual on Rod Control System. Take unit off load control.

D. Control power and stationary Gripper power will be energized and will present a shock hazard to maintenance personnel. Extreme caution must be taken to prevent coming in contact with live buses.

E. The power circuit in each power cabinet is approximately 260 V a.c. When maintenance is performed on the main power circuits of the power cabinets, test equipment with differential inputs should be used for personnel safety. Test equipment such as the Fluke digital voltmeter (Models 8120A and 8400); Tektronix Oscilloscope (Model 5103N), using a differential amplifier (Model 5A20N); Honeywell visicorder (Model 1508B), using d.c. amplifier (Model 122); and Gould Brush recorder (Model 260) have differential inputs and should be used if possible.

If test equipment not having differential inputs is used, the third ground wire on the test equipment power cord must be disconnected by inserting a three-to-two prong plug adapter. EXTREME CAUTION must be taken because the chassis of the test equipment will be approximately 260 V d.c. Specific approval of the Instrument and Control Supervisor must be obtained prior to use of nondifferential input equipment.

F. Do not perform preventive maintenance on stationary grippers unless the reactor is tripped.

PREPARING SYSTEM FOR ISOLATION

A. Obtain permission from the Control Operator to remove the Power Cabinet from service.

B. Check that the following lights are illuminated on the d.c. Hold Cabinet:
   1. a.c. power on.
   2. 125 V on.
   3. 70 V on.

C. On the Power Cabinet being isolated, open the following bus disconnects:
   1. Lift Coil (A101).
   2. Movable Coil (A102).

D. If maintenance on the movable gripper on lift coil sections is desired, there is no requirement for a group to be placed on the "d.c. Hold Bus."
   If maintenance on the stationary gripper or printed circuit boards is desired, perform steps E through H.

E. Place the "Group Hold" switch, for the group being isolated, in the "Latch" position for a few seconds and then to the "Hold" position.

F. CAUTION.
   Ensure that the group is on the "d.c. Hold Bus" before removing the three Stationary Gripper input fuses.
   DO NOT remove the Stationary Gripper fuses for the other two groups in the Power Cabinet, as this will cause rods to drop. If work is to be done on any printed circuit boards, remove only the printed circuit cards associated with the group on the "d.c. Hold Bus."

G. There are blown-fuse indicators in parallel with all Stationary Gripper input fuses in the Power Cabinet. Remove the following three blown-fuse indicators associated with the group on the "d.c. Hold Bus":

Group A	Group B	Group C
A65DS1	A66DS1	A67DS1
A65DS2	A66DS2	A67DS2
A65DS3	A66DS3	A67DS3

H. Remove the three Stationary Gripper input fuses located in the Power Cabinet for the group on the "d.c. Hold Bus":

Group A	Group B	Group C
FU1	FU4	FU7
FU2	FU5	FU8
FU3	FU6	FU9

MAINTENANCE

A. Perform maintenance per section 3 of Westinghouse Full Length Rod Control System manual.

B. Check tightness on terminals of all current-sampling resistors in the lift- and movable-coil circuits.

C. CAUTION:
Check tightness of the stationary-coil, current-sampling resistors to the terminal block *only* in the *reactor trip condition*.

1. Lift-coil, sampling-current resistors are —
A50-R1
A50-R2
A50-R3
A50-R4

Movable-coil, sampling-current resistors are –

A49-R1

A49-R2

A49-R3

A49-R4

2. Stationary-coil, sampling-current resistors are –

Group A	Group B	Group C
A46-R1	A47-R1	A48-R1
A46-R2	A47-R2	A48-R2
A46-R3	A47-R3	A48-R3
A46-R4	A47-R4	A48-R4

RETURNING SYSTEM TO NORMAL

A. Ensure that all printed circuit cards are installed.

B. Install the three Stationary Gripper input fuses located in the Power Cabinet if removed previously.

Group A	Group B	Group C
FU1	FU4	FU7
FU2	FU5	FU8
FU3	FU6	FU9

C. Install the three blown-fuse indicators in parallel with the Stationary Gripper input fuses if removed previously.

Group A	Group B	Group C
A65DS1	A66DS1	A67DS1
A65DS2	A66DS2	A67DS2
A65DS3	A66DS3	A67DS3

D. Place the "Group Hold" switch in the "OFF" position.

E. Reclose the following bus disconnects:
   1. Lift Coil (A101).
   2. Movable Coil (A102).

F. Reset the Power Cabinet "Urgent Alarm" if energized.

G. Request the Control Operator to place the Rod Control System in AUTOMATIC.

H. Inform the Control Operator the Power Cabinet is back in service.

APPENDIX C

ELECTROPNEUMATIC INSTRUMENT AND CONTROL EQUIPMENT MAINTENANCE

TYPICAL STEAM ELECTRIC STATION
INSTRUMENT & CONTROL MANUAL

SAFETY-RELATED

ELECTROPNEUMATIC INSTRUMENT AND
CONTROL EQUIPMENT MAINTENANCE

Procedure No. INC-202
Revision No. 0

SUMITTED BY: ________________________ DATE: ______
INSTRUMENT & CONTROL ENGINEER

APPROVED BY: ________________________ DATE: ______
CPSES GENERAL SUPERINTENDENT

Instrument & Control Equipment	ISSUE DATE __________	PROCEDURE NO. INC-202
Electropneumatic Instrument and Control Equipment Maintenance	REVISION NO. 0	PAGE 2 OF 5

PURPOSE

The purpose of this procedure is to provide guidelines for the maintenance and calibration of electropneumatic instrument and control equipment.

APPLICABILITY

This procedure applies to all installed electropneumatic instrument and control equipment after turnover to CPSES Startup or Operations. This procedure becomes effective when issued.

DEFINITIONS

None.

INSTRUCTIONS

Working Documents

1. Procedure INC-101, "I & C Maintenance and Calibration Program."

2. Applicable manufacturer's instructions, bulletins, technical manuals, or instruction books.

PREREQUISITES

1. Obtain clearance from the shift supervisor or designee before proceeding with maintenance activities.

PRECAUTIONS, LIMITATIONS, AND SPECIAL CONDITIONS

1. Safety precautions must be observed at all times when working with or around electrical and pressurized equipment or instruments or in radiation zones.
2. Measuring and test equipment must be calibrated in accordance with Procedure INC-102, "I & C Measuring and Test Equipment Program."
3. If any safety-related instrument or control equipment is found defective or damaged, notify the I & C Engineer designee before proceeding with repair or replacement.

Instrument & Control Equipment	ISSUE DATE ______	PROCEDURE NO. INC-202
Electropneumatic Instrument and Control Equipment Maintenance	REVISION NO. 0	PAGE 4 OF 5

MTE/Tool List

None.

PREPARATIONS

1. Ensure that current calibration data for the instrument or control equipment is used.
2. Ensure that instrument or control equipment, associated system, calibration data, and references listed above are thoroughly understood before proceeding with maintenance activities.
3. Isolate instrument or control equipment properly, noting precautions in manufacturer's manual. If the instrument or control equipment is safety-related, isolate the respective channel in accordance with applicable subsections of the section entitled "Preparation" of the appropriate I & C surveillance test procedure and note precautions stated therein.

Instrument & Control Equipment	ISSUE DATE __________	PROCEDURE NO. INC-202
Electropneumatic Instrument and Control Equipment Maintenance	REVISION NO. 0	PAGE 5 OF 5

PERFORMANCE

1. Remove dust or dirt from instrument with dust cloth, brush, low-pressure air (>30 psi), or vacuum cleaner.
2. Ensure that sensing line fittings are tight and have no leaks. Check lines for signs of excessive vibration.
3. Ensure that all electrical connections, plugs, and connectors are tight and show no signs of damage or deterioration.
4. Inspect circuit boards for cracking or chipping and burned or leaking components. Repair or replace as necessary. (See section on "Precautions, Limitations, and Special Conditions," Number 3.)
5. Ensure that electrical wiring does not interfere with linkage movement.
6. Inspect mechanical moving devices for freedom of movement and excessive wear. Lubricate as necessary.
7. On diaphragm-actuated equipment, ensure that the diaphragms are pliable and, when in place, are not leaking around the seals.
8. Ensure that air-regulator filters are clean and that each regulator is supplying the required air pressure to each instrument.

9. Calibrate according to manufacturer's specification or to a specific instrument calibration procedure as noted on the associated Instrument and Control Equipment Data Sheet. Calibrate to values shown on the associated data sheet and verify actuation of associated alarm, if practical.

ACCEPTANCE CRITERIA

1. Specified tolerances for calibration of instrument or control equipment must be met. If repair or replacement is required, specified tolerances for subsequent calibrations must be met.
2. Repaired or replaced safety-related instrument or control equipment must meet original specifications.

POST INSTRUCTION

1. Return instrument or control equipment to service, noting precautions in manufacturer's manual. If the instrument or control equipment is safety-related, return the respective channel to service in accordance with applicable subsections of the section entitled

"Post Instructions" of the appropriate I & C surveillance test procedure, and note precautions stated therein.

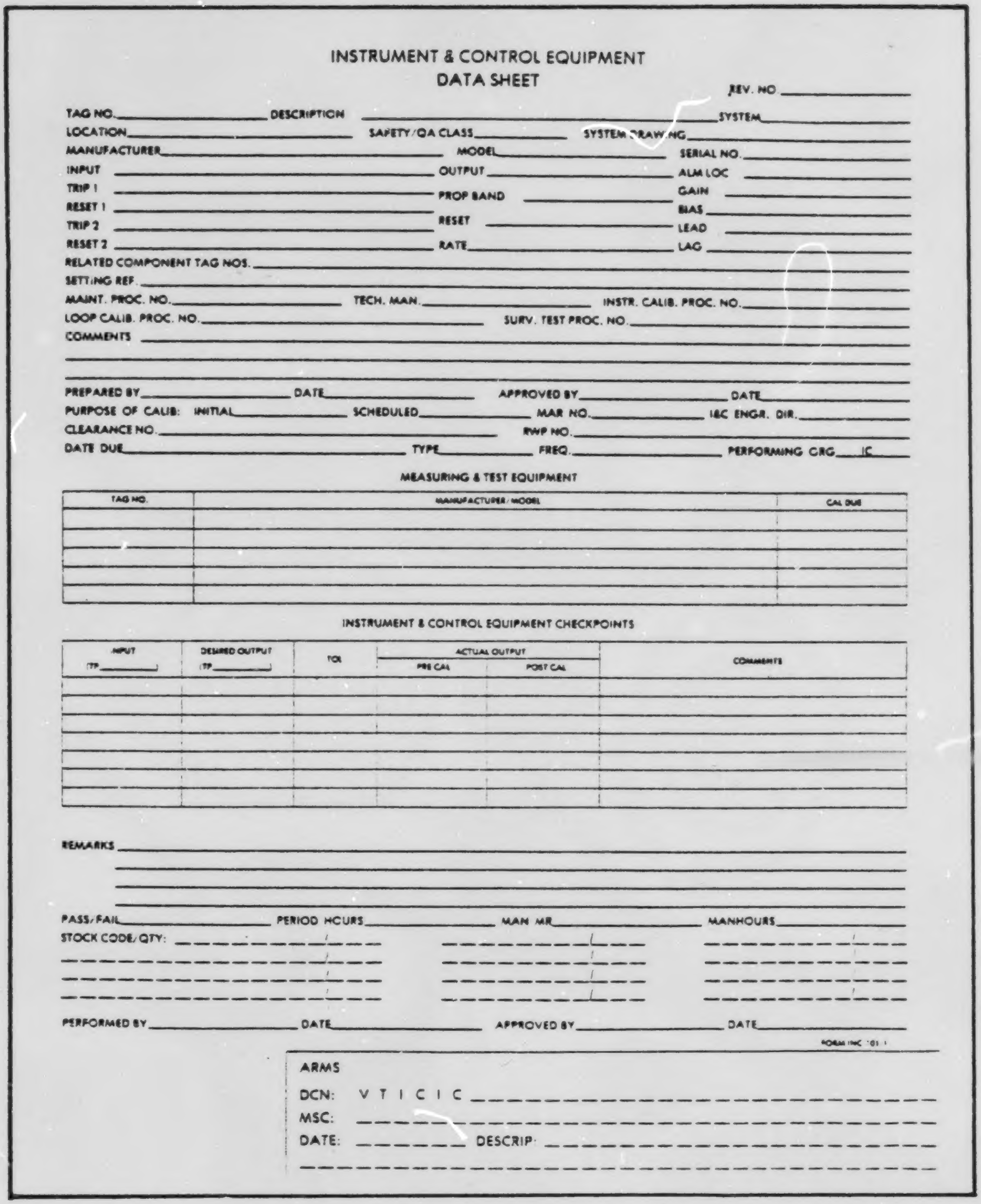
2. Submit complete Instrument and Control Equipment Data Sheet to the I & C Engineer or designee for approval.
3. Release clearance to the shift supervisor or designee.

REFERENCES

1. Procedure INC-101, "I & C Maintenance and Calibration Program."
2. Procedure INC-102, "I & C Measuring and Test Equipment Program."
3. Procedure SAF-004, "Clearance and Safety Tagging."
4. Procedure HPG-004, "Radiation Work Permits."
5. Procedure STA-202, "Preparation, Review, Approval and Revision of Station Procedures."

ATTACHMENTS

None.



INSTRUMENT & CONTROL EQUIPMENT
DATA SHEET

REV. NO. ____________

TAG NO. ____________ DESCRIPTION ____________ SYSTEM ____________
LOCATION ____________ SAFETY/QA CLASS ____________ SYSTEM DRAWING ____________
MANUFACTURER ____________ MODEL ____________ SERIAL NO. ____________
INPUT ____________ OUTPUT ____________ ALM LOC ____________
TRIP 1 ____________ PROP BAND ____________ GAIN ____________
RESET 1 ____________ BIAS ____________
TRIP 2 ____________ RESET ____________ LEAD ____________
RESET 2 ____________ RATE ____________ LAG ____________
RELATED COMPONENT TAG NOS. ____________
SETTING REF. ____________
MAINT. PROC. NO. ____________ TECH. MAN. ____________ INSTR. CALIB. PROC. NO. ____________
LOOP CALIB. PROC. NO. ____________ SURV. TEST PROC. NO. ____________
COMMENTS ____________

PREPARED BY ____________ DATE ____________ APPROVED BY ____________ DATE ____________
PURPOSE OF CALIB: INITIAL ____________ SCHEDULED ____________ MAR NO. ____________ I&C ENGR. DIR. ____________
CLEARANCE NO. ____________ RWP NO. ____________
DATE DUE ____________ TYPE ____________ FREQ. ____________ PERFORMING ORG. IC

MEASURING & TEST EQUIPMENT

TAG NO.	MANUFACTURER/MODEL	CAL DUE

INSTRUMENT & CONTROL EQUIPMENT CHECKPOINTS

INPUT (TP ______)	DESIRED OUTPUT (TP ______)	TOL	ACTUAL OUTPUT		COMMENTS
			PRE CAL	POST CAL	

REMARKS ____________

PASS/FAIL ____________ PERIOD HOURS ____________ MAN HR ____________ MANHOURS ____________
STOCK CODE/QTY: ____________

PERFORMED BY ____________ DATE ____________ APPROVED BY ____________ DATE ____________

FORM I&C 101-1

ARMS
DCN: V T I C I C ____________
MSC: ____________
DATE: ____________ DESCRIP: ____________

Figure 35-6-3. Typical instrument and control data sheet.

TEST

1. Define the following terms:
   a. Maintenance.

   b. Preventive maintenance.

   c. Corrective maintenance.

   d. Overhaul maintenance.

   e. Calibration.

   f. Surveillance test.

2. Describe the purpose and safety aspects of general maintenance inspection procedures.

3. List the elements of documentation and the scheduling methods for preventive maintenance.

ELEMENTS OF DOCUMENTATION	SCHEDULING METHODS

4. Explain the purpose of planning equipment or system clearances in a preventive maintenance system.

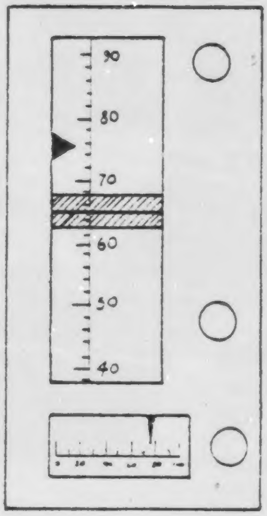
5. Discuss the purpose of planning information or data recording in a preventive maintenance system.

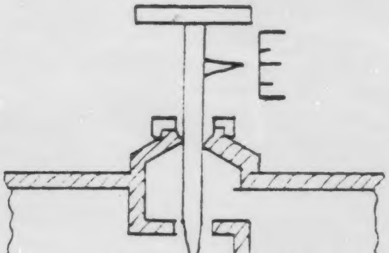
6. How does quality control interface with an effective PM system?

NUCLEAR TECHNOLOGY

MODULE 35-7

INSTRUMENT RELIABILITY





SYSTEMS AND COMPONENTS

COURSE 35

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

CONTENTS

COURSE 35 SYSTEMS AND COMPONENTS

MODULE 35-1 Electrical Distribution
MODULE 35-2 Instrumentation and Control for Major Plant Components
MODULE 35-3 Recording and Display Devices
MODULE 35-4 Process Control Loops and Devices
MODULE 35-5 Cathode-Ray Tube Systems (CRT)
MODULE 35-6 Preventive Maintenance for Systems and Components
MODULE 35-7 Instrument Reliability

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INTRODUCTION

As the student knows, operation of a nuclear power plant would be impossible without the proper functioning of a wide variety of instruments. Such instruments provide vital indications of conditions, performance, position, and direction; some of them even control important processes. Therefore, instruments of the proper design must be correctly installed and carefully maintained and tested.

This module explains the fundamentals of instrument reliability and how electrical codes and standards, practical design, installation, and maintenance/testing programs and procedures develop and maintain such reliability. This module also describes how quality-assurance and quality-control requirements in the nuclear power industry enhance instrument reliability.

MODULE PREREQUISITES

The student should have completed Course 3, "Principles of Process Instrumentation"; Course 6, "Instrumentation and Control of Reactors and Plant Systems"; Course 14, "Introduction to Quality Assurance/Quality Control"; and the previous modules in this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
    - Reliability.
    - Quality.
    - Standard.
    - Regulatory Guide.
    - Class 1E.
2. Explain preinstallation instrument application design criteria.
3. Describe preinstallation verification.
4. Prepare a simple procedure for installation and checks of an electronic pressure transmitter.
5. Discuss the purpose of calibration.
6. List the major electrical codes and standards used in power plant instrumentation; explain where they are applicable.
7. Explain how quality-assurance/quality-control verification interfaces in all aspects of instrument reliability.
8. Using manufacturer's procedures, calibrate the following types of instruments:
    - Pressure transmitter.
    - Resistance temperature detector.
    - Turbine flowmeter.

DEFINITIONS

- Reliability is the characteristic of an item expressed by the probability that it will perform a required service under stated conditions for a stated service time.
- Quality is the extent of conformance to specifications of an item to perform a required service.
- Standard is the criteria established for the design, construction, engineering, installation, calibration, and/or testing of an item approved by a professional organization(s) for use in industry.
- Regulatory Guide is the criteria, guidance and/or approval of nuclear industry standards provided by the Nuclear Regulatory Commission (NRC) for use in nuclear applications.
- Class 1E is the safety classification of the electric equipment and systems essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or otherwise essential in preventing significant release of radioactive material to the environment.

INSTRUMENT ENGINEERING

Instrument reliability is established in three basic phases none of which can ensure reliability without the others. These phases are —

- Design.
- Installation.
- Maintenance/testing.

Each phase is governed by engineering criteria or parameters, industry standards, and regulatory guides for the particular application involved. With the proper completion of each phase, the instrument reliability established will aid in the establishment of the highest plant-production efficiency attainable. However, in the nuclear power industry, instrument reliability has the additional role of enhancing plant safety.

DESIGN

Instruments are designed by model for use in most of the wide range of applications encountered in industry. However, to design and manufacture an instrument for a specific and rarely-encountered application is not cost effective. Since the design phase is the initial phase and, therefore, has the greatest effect for enhancing reliability and safety, the design of an instrument model must meet the engineering criteria and specifications for the range of applications involved.

Depending upon the instrument type, the design initially entails specification items such as pressure, temperature, type of fluid, fluid viscosity and specific gravity, type of sensor, sensor material, site, range, location in equipment or piping, etc. Each item, although seemingly irrelevant, ensures proper application of the instrument and, therefore, contributes to its reliability.

For an instrument such as the turbine flowmeter, the following mechanical, electrical, and performance design characteristics would be specified:

- Measured fluid.
- Minimum and maximum temperatures.
- Pressure.
- Speed.
- Electrical excitation and output.
- Range.
- Sensitivity.
- Linearity.
- Pressure drop.

Design criteria as set forth by industry standards for instrument and control equipment include those listed in Table 35-7-1. Table 35-7-2 lists those industry standards and regulatory guides for nuclear power plant instrument design.

A comparison of Table 35-7-1 to Table 35-7-2, reveals that instrument design criteria is much more extensive in nuclear applications than in any other. This fact is more readily apparent in the IEEE Standard 323-1974 – "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations" – than in any standard yet published for the nuclear industry. IEEE Standard 279-1971 – "IEEE Standard Criteria for Protection Systems for Nuclear Power Generating Stations" – establishes the minimum design criteria for instrument-and-control equipment in nuclear power applications and provides for a high level of performance and reliability. IEEE 323-1974 establishes the criteria for the qualifications of design and manufacturing processes of instrument-and-control equipment to attain the high degree of confidence that future instrument-and-control equipment of the same type will perform as required for the time period specified. Therefore, IEEE 323-1974 qualifies the reliable performance of instrument-and-control equipment for emergency shutdown of the reactor, isolation of containment, cooling

TABLE 35-7-1
INSTRUMENT DESIGN STANDARDS

STANDARD NO.	TITLE
ANSI/ASME B40.1-74	Gages – Pressure and Vacuum Indicating Dial Type – Elastic Element
ANSI/ASME B40.1M-79	Gauges – Pressure Indicating Dial Type – Elastic Element (Metric)
ANSI/ASME B40.2-77	Gauges and Indicators Pressure and Vacuum Indicating Digital Type
ANSI B131.1-72 (UL 873-72)	Temperature – Indicating and Regulating Equipment
ANSI C39.1-72	Requirements for Electrical Analog Indicating Instruments
ANSI C39.2-64	Direct – Acting Electrical Instruments (Switchboard and Portable Types)
ANSI C39.3-76	Shock Testing for Electrical Indicating Instruments
ANSI C39.4-66	Automatic Null-Balancing Electrical Measuring Instruments
ANSI C39.5-74	Electrical and Electronic Measuring & Controlling Instrumentation, Safety Requirements for
ANSI/IEEE C57.13-78	Requirements for Instrument Transformers
ANSI C39.6-69	Requirements for Automatic Digital Voltmeters and Ratio Meters
ANSI C39.7-75	Electronic Analog Voltmeters, Requirements For
ANSI/IEEE C57.13-78	Requirements for Instrument Transformers
ANSI MC6.2-75 (ISA S37.3-70	Tests for Strain Gage Pressure Transducers Specification
ANSI MC6.3-75 (ISA S37.5-71)	Standard for Specifications and Tests for Strain Gage Linear Acceleration Transducers
ANSI MC6.4-75 (ISA S37.10-1969)	Piezoelectric Pressure Transducers, Specifications and Tests for
ANSI MC6.5-76 (ISA S37.6-75)	Potentiometric Pressure Transducers, Specifications and test of
ANSI MC12.1-75 (ISA S50.1-1975)	Compatibility of Analog Signals for Electronic Industrial Process Instruments
ANSI/ISA MC96.1-75	Temperature Measurement Thermocouples
ASME PTC 19.2-64	Pressure Measurement
ASME PTC 19.3-74	Temperature Measurement Instruments & Apparatus Part 3
ASME PTC 19.5-71	Application Part II of Fluid Meters
ASME PTC 19.6-55	Electric Measurements
ASME PTC 20.3-70	Pressure Control Systems Used on Steam Turbine-Generator Units
IEEE 61-77	National Electric Safety Code

Table 35-7-1. Continued.

(ANSI C2.1-71, C2.2-76, C2.3-23, C2.4-73)	
IEEE 338-77	Periodic Testing of Nuclear Power Generating Station Safety Systems, Standard Criteria for the
ISA RP3.1-51	Recommended Practice for Flowmeter Installations Seal and Condensate Chambers
ISA RP3.2-56	Recommended Practice, Flange Mounted Sharp Orifice Plates for Flow Measurement
ISA RP12.1-60	Recommended Practice for Electrical Instruments in Hazardous Atmospheres
ANSI/ISA RP12.6-77	Recommended Practice for Installation of Intrinsically Safe Instrument Systems in Class 1 Hazardous Locations
ISA RP16.5-61	Tentative Recommended Practice for Installation, Operation, Maintenance Instructions for Glass Tube Variable Area Meters (Rotameters)
ANSI/ISA RP31.1-77	Recommended Practice for Specification, Installation, and Calibration of Turbine Flowmeters
ISA RP60.08-78	Recommended Practice Electrical Guide for Control Centers
ISA S12.11-73	Standard for Electrical Instruments in Hazardous Dust Locations
ISA S37.8-75 (ANSI S37-8-77)	Standard for Specifications and Tests for Strain Gage Force Transducers
ISA S37.12-77	Standard for Specifications and Tests for Potentiometric Displacement Transducers
NEMA E12-66	Instrument Transformers
ANSI/NEMA ICS1-79	General Standards for Industrial Control and Systems
ANSI/NEMA ICS2-79	Industrial Control Devices, Controllers and Assemblies

TABLE 35-7-2
CLASSIC INSTRUMENT DESIGN STANDARDS[1]
(Nuclear Only)

STANDARD NO.	TITLE
ANSI N42.7-72 (IEEE 279-71)	Criteria for Protection Systems for Nuclear Power Generating Stations
ANSI/IEEE 308-74	Standard Criteria for Class IE Power Systems for Nuclear Power Generating Stations
IEEE 323-74	Qualifying Class IE Equipment for Nuclear Power Generating Stations
IEEE 344-75	Seismic Qualification of Class I Electric Equipment for Nuclear Power Generating Station
ANSI/IEEE 352-75	General Principles for Reliability Analysis of Nuclear Power Generating Station Protection Systems
IEEE-379-77	Application of the Single Failure Criterion to Nuclear Power Generating Station Class IE Systems
IEEE 381-77	Criteria for Type Tests of Class IE Modules Used in Nuclear Power Generating Stations
IEEE 384-77	Criteria for Separation of Class IE Equipment and Circuits
IEEE 420-73 (ANSI N41.17-73)	Guide for Class IE Control Switchboards for Nuclear Power Generating Stations
IEEE 497-77 (ANSI N41.26-77)	Post Accident Monitoring Instrumentation for Nuclear Power Generating Stations
IEEE 566-77	Design of Display and Control Facilities for Central Control Rooms of Nuclear Power Generating Stations
ANSI/IEEE 577-76	Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations
IEEE 603-77	Criteria for Safety Systems for Nuclear Power Generating Stations
ANSI/IEEE N13.10-74	Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents
ISA RP25.1-57	Tentative Recommended Practice, Materials for Instruments in Radiation Service
GDC[2] 4	Environment and Missile Design Bases
GDC 13	Instrumentation and Control
GDC 21	Protection System Reliability and Testability
GDC 22	Protection System Independence
GDC 23	Protection System Failure Modes

Table 35-7-2. Continued.

GDC 24	Separation of Protection and Control Systems
RG[3] 1.11	Instrument Lines Penetrating Primary Reactor Containment
RG1.12	Instrumentation for Earthquakes
RG1.29	Seismic Design Classification
RG1.53	Application of the Single Failure Criterion to Nuclear Power Plant Protection Systems
RG1.89	Qualification of Class IE Equipment for Nuclear Power Plants
RG1.97	Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant Conditions During & Following an Accident
RG1.100	Seismic Qualification of Electric Equipment for Nuclear Power Plants
RG1.105	Instrument Spans and Setpoints
BTP[4] EICSB23	Qualification of Safety-Related Display Instrumentation for Post-Accident Condition Monitoring and Safe Shutdown

[1] Table 35-7-1 Standards also apply
[2] General Design Criteria (GDC)
[3] NRC Regulatory Guide (RG)
[4] Branch Technical Position (BTP) EICSB

of the reactor core, and/or prevention of the release of significant radioactive material into the environment. This standard addresses the environmental and seismic criteria for this type of equipment. Environmental conditions entail normal ambient and atmospherical conditions experienced in nuclear power plants. However, in-containment instrument-and-control equipment must qualify to a sequence of varying pressures, temperatures, radiation, steam and water, atmospheric, and seismic criteria, as specified by IEEE 323-1974. Refer to Appendix A for test program for RTD and thermocouple assemblies.

The IEEE standards mentioned apply generically to instruments used in Class 1E applications at nuclear power plants. However, some industry standards apply specifically to the design of types of instruments. From ANSI/ISA-RP31-1 for the turbine flowmeter example, the recommended practice is as follows: Specification, installation, and calibration of turbine flowmeters applies, in design and engineering, to the proper specification and application of this instrument for non-Class 1E usage (as does ASME Standard PTC 19.5-71 – Application Part II of Fluid Meters).

INSTALLATION

Although the design and application of an instrument may be sound, improper installation of the instrument could contribute not only to its direct unreliability, but would have the most profound effect upon total system operation reliability. Therefore, an instrument must be properly installed to enhance the reliability of the instrument and all associated systems.

Instrument installation entails (1) receipt inspection of instruments and (2) installation procedures. Receipt inspection involves such actions as —

- Careful removal of slipping stops, if any.
- Verification that manufacturer and identification type, as indicated on the instrument, agree with purchase order.
- Visual check for damage to casings.
- Testing of grounding, shorts, and continuity of electrical circuits.

Functional testing or calibration could be performed as part of the inspection procedure, although it is performed after installation. Installation procedures are developed from three sources:

- Manufacturer.
- Designer or engineer.
- Constructor or installer.

The manufacturer provides recommended instrument mounting position and bracket for the application desired: An example is provided in Figure 35-7-1 for an electronic pressure transmitter. The designer, using the manufacturer's mounting recommendation, physically locates the instrument in the plant. Several factors that must be considered in locating an instrument such as the electronic differential pressure transmitter are —

- The position of the instrument in relation to the measured process.
- The routing of impulse lines for protection against air entrapment and pipe or equipment impingement in nuclear applications.
- The environmental conditions of the area.

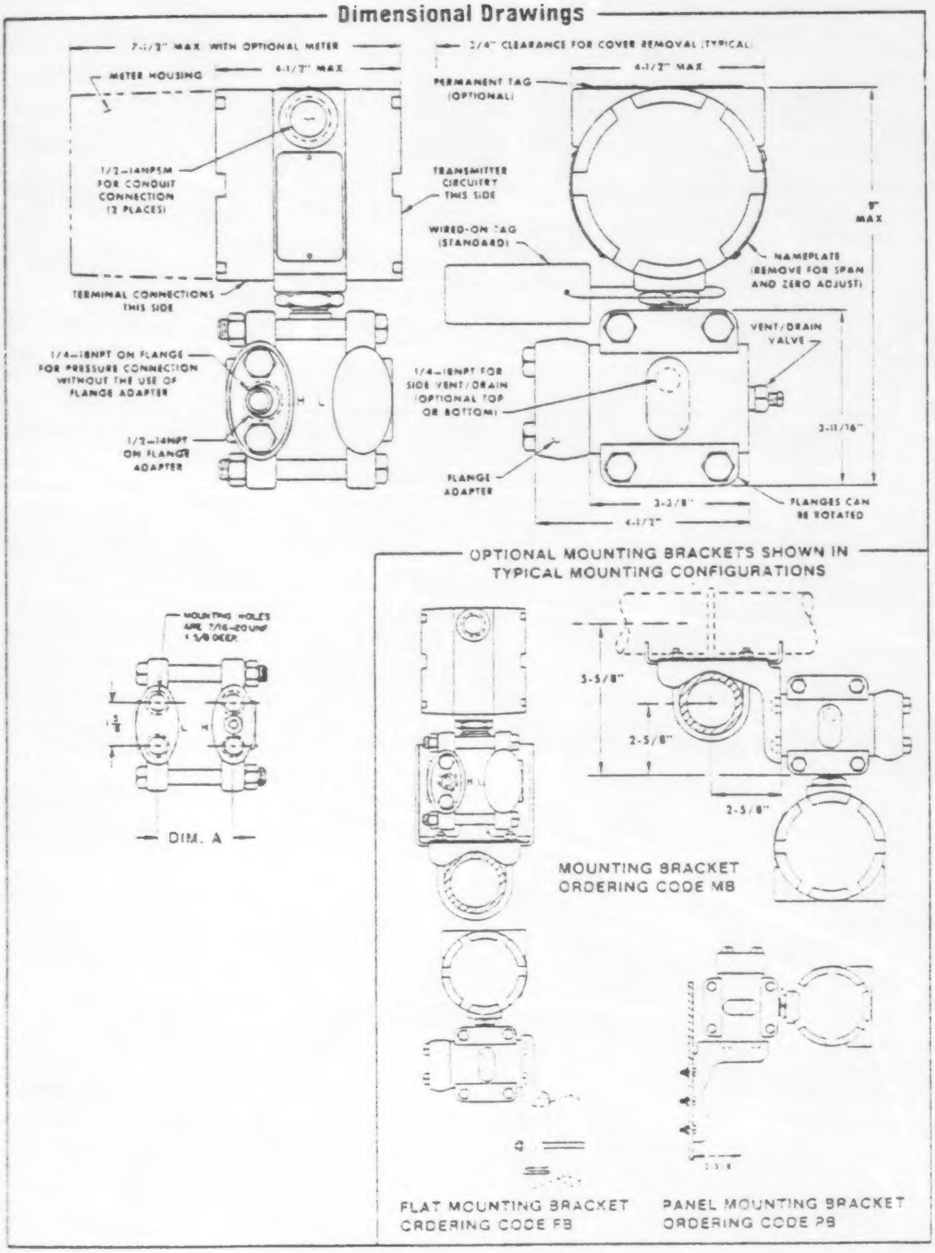

Dimensional Drawings
7-1/2" MAX WITH OPTIONAL METER
4-1/2" MAX
METER HOUSING
1/2–14NPSM FOR CONDUIT CONNECTION (2 PLACES)
TRANSMITTER CIRCUITRY THIS SIDE
TERMINAL CONNECTIONS THIS SIDE
1/4–18NPT ON FLANGE FOR PRESSURE CONNECTION WITHOUT THE USE OF FLANGE ADAPTER
1/2–14NPT ON FLANGE ADAPTER
H
L
3/4" CLEARANCE FOR COVER REMOVAL (TYPICAL)
4-1/2" MAX
PERMANENT TAG (OPTIONAL)
WIRED-ON TAG (STANDARD)
9" MAX
NAMEPLATE (REMOVE FOR SPAN AND ZERO ADJUST)
VENT/DRAIN VALVE
1/4–18NPT FOR SIDE VENT/DRAIN (OPTIONAL TOP OR BOTTOM)
3-11/16"
FLANGE ADAPTER
3-3/8"
4-1/2"
FLANGES CAN BE ROTATED
MOUNTING HOLES ARE 7/16–20 UNF × 3/8 DEEP
DIM. A
OPTIONAL MOUNTING BRACKETS SHOWN IN TYPICAL MOUNTING CONFIGURATIONS
5-5/8"
2-5/8"
2-5/8"
MOUNTING BRACKET ORDERING CODE MB
FLAT MOUNTING BRACKET ORDERING CODE FB
PANEL MOUNTING BRACKET ORDERING CODE PB

Figure 35-7-1. Pressure transmitter mounting.

- The plant equipment interferences.
- The measured process makeup or condition to protect the instrument against exposure to steam or acidic fluids.

Figure 35-7-2 depicts a typical measurement system for steam-generator level at a nuclear plant. An electronic differential transmitter is utilized with this sytem. Normally, the physical location and mounting of the instrument and routing of impulse lines are illustrated in instrument-location diagrams developed by the designer.

Ideally, all instruments should be installed according to specifications, drawings, and instrument lists. However, the constructor deals with the "real world" and on occasion discovers that the location or mounting of the instrument or routing of the impulse lines will not suffice because of equipment interferences or other structural problems. In the resolution of these types of problems, the constructor must ensure that the instrument operability and reliability are not impaired. Usually, modifications of design are reviewed and approved by the designer. This review process is required in the construction of nuclear power plants.

There are several instrument installation contingencies that are the contractor's responsibilities, as these could not be anticipated or designed for by either manufacturer or designer. Such contingencies consist of the following:

- Workmanship.
- Prevention of installing damaged instruments.
- Care in handling and installing instruments.
- Fabrication of instrument supports.
- Prevention of supporting instruments by the use of tubing, fittings, or valve hookups.

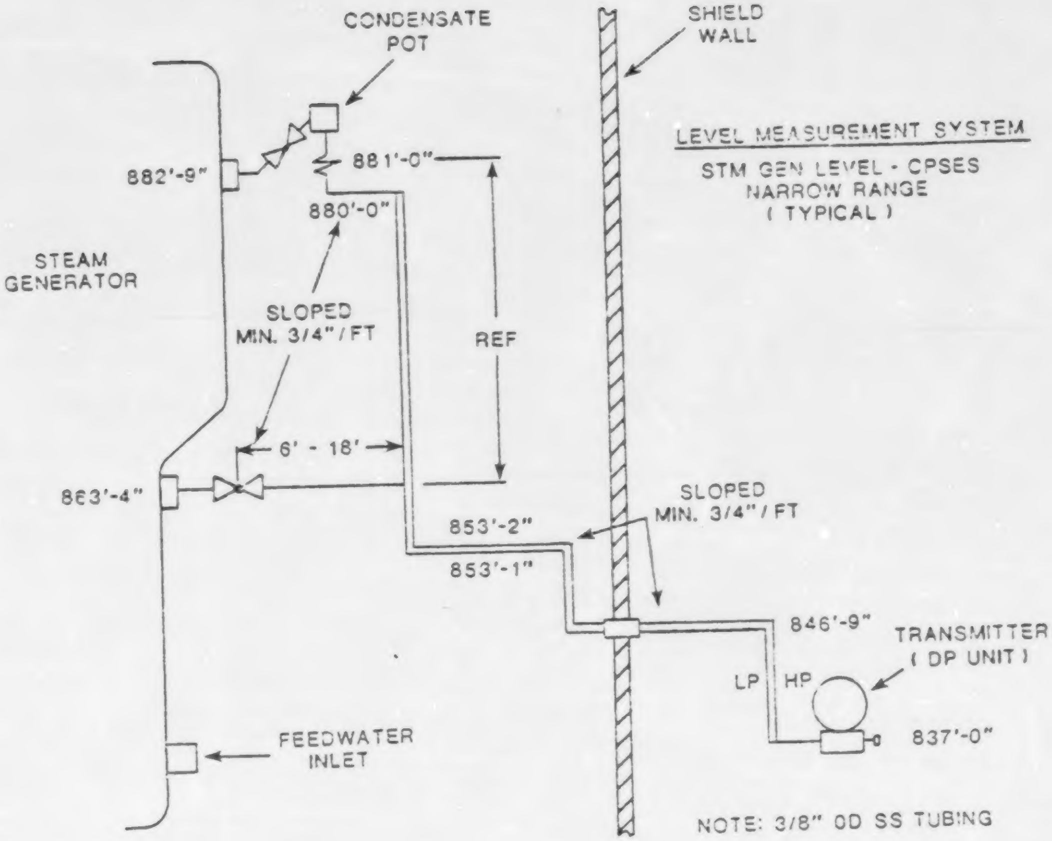

CONDENSATE POT
SHIELD WALL
LEVEL MEASUREMENT SYSTEM
STM GEN LEVEL - CPSES
NARROW RANGE
(TYPICAL)
882'-9"
881'-0"
880'-0"
STEAM GENERATOR
SLOPED MIN. 3/4"/FT
REF
6' - 18'
863'-4"
SLOPED MIN. 3/4"/FT
853'-2"
853'-1"
846'-9"
TRANSMITTER (DP UNIT)
LP
HP
837'-0"
FEEDWATER INLET
NOTE: 3/8" OD SS TUBING

Figure 35-7-2. Level measurement system for steam-generator level.

- Protection of instruments from dirt, freezing weather, corrosion, acid, and construction traffic or area work during the construction period.
- External cleaning of instruments after installation. Such cleaning is especially required after installation of thermowells and prior to the insertion of the temperature-sensing element.

The turbine flowmeter to which reference has been made provides a good example for proper instrument installation. Proper installation could be considered the constructor's responsibility because of inadequate physical piping configurations provided the designer. In such a situation, the constructor must verify that the flowmeter is installed in the associated piping at a minimum of 20 and 5 pipe diameters of straight line upstream and downstream, respectively. This installation would ensure proper instrument operation and, therefore, reliability and would be in conformance with ANSI/15A-RP31.1 previously mentioned.

Obviously, therefore, installation procedures are a viable means of attaining instrument reliability. Standards that apply to instrument installation are listed in Table 35-7-3.

MAINTENANCE/TESTING

Regardless of how well an instrument is designed, manufactured and installed, reliability cannot be ensured unless proper maintenance is periodically performed on that instrument. In addition, measuring and test equipment (M & TE) used in maintenance activities must be calibrated periodically to validate the maintenance performed on instruments.

Maintenance/testing of both M & TE and instruments consists of three maintenance categories:

- Calibration.
- Preventive maintenance.
- Surveillance test.

TABLE 35-7-3
INSTRUMENT INSTALLATION STANDARDS
(Nuclear & Others)

STANDARD NO.	TITLE
ANSI/ASME N45.2.2-78	Packaging, Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants
ANSI/ASME N45.2.3-73	Housekeeping During the Construction Phase of Nuclear Power Plants
IEEE 336-77	Installation, Inspection, and Testing Requirements for Instrumentation and Electric Equipment During Construction of Nuclear Power Generating Stations
IEEE 415-76	Planning of Preoperational Testing Programs for Class IE Power Systems for Nuclear Power Generating Stations, Guide for
ISA RP3.1-51	Recommended Practice for Flowmeter Installations Scale and Condensate Chambers
ANSI/ISA RP12.6-77	Recommended Practice for Installation of Intrinsically Safe Instrument Systems in Class 1 Hazardous Locations
ISA RP16.5-61	Tentative Recommended Practice for Installation, Operation, Maintenance Instructions for Glass Tube Variable Area Meters (Rotameters)
ANSI/ISA RP31.1-77	Recommended Practice for Specification, Installation, and Calibration of Turbine Flowmeters
RG1.68	Initial Test Programs for Water-Cooled Reactor Power Plants

Calibration and preventive maintenance of instrument-and-control equipment were discussed and procedures were developed in Module 35-6, "Preventive Maintenance for Systems and Components." In a similar manner, calibration and maintenance of M & TE will be discussed here. Surveillance testing applies more to instruments than to M & TE and, therefore, will be discussed in relation to instrument-and-control equipment.

As was briefly mentioned previously, an important contribution to instrument reliability is the proper and periodic calibration and maintenance of M & TE. M & TE are, in turn, used to calibrate, maintain, and test instrument-and-control equipment. Therefore, M & TE should –

- Be of greater accuracy than the instrument-or-control equipment being calibrated.
- Be rugged for field use.
- Be calibrated and maintained periodically.
- Be calibrated by standards traceable to the National Bureau of Standards or by some natural physical constant.

An example of a calibration procedure is provided in Appendix B. This procedure applies to the calibration of the Fluke 8600A Digital Multimeter and is part of INC-102-I & C Measuring and Test Equipment Program, which requires a 6-month calibration cycle. Sections of the Fluke 8600A manual, referenced in procedure INC-601-Fluke 8600A Digital Multimeter Calibration, also are provided in Appendix B for ease of review of the procedure. Any maintenance required is performed prior to the calibration of M & TE and by adherence to the instructions provided in the equipment manual.

This procedure ensures reliability of the Fluke 3600A and establishes a high confidence level when it is utilized to calibrate and enhance the reliability of instrument-and-control equipment.

Standard IEEE-498-75 — "Requirements for the Calibration and Control of Measuring and Test Equipment used in the Construction and Maintenance of Nuclear Power Generating Stations" — pertains to M & TE calibration and maintenance. Standards and regulatory guides pertaining to instrument-and-control equipment are listed in Table 35-7-4.

Surveillance testing was defined in Module 35-6 in order to point out the additional maintenance required for Class 1E (or safety-related) instrument-and-control equipment of nuclear power facilities to ensure reliability in protective equipment and systems. It encompasses the periodic functional and response-time testing of instrument-and-control equipment and consists of —

- Physical inspections.
- Circuit continuity checks.
- Calibration checks.
- Actuation of instrument switches (pressure, temperature, flow, etc).
- Actuation of sensors (instruments) to verify response times.

The qualification test program of Appendix A includes required periodic surveillance inspection and testing to maintain the Class 1E RTD and thermocouple assemblies in a "qualified" and, therefore, reliable condition. Section 7.2.1 of this program lists the required surveillance and is indicative of the surveillance testing performed on Class 1E instruments to ensure the reliability required of protective equipment at nuclear power plants.

TABLE 35-7-4
INSTRUMENT CALIBRATION & MAINTENANCE STANDARDS
(Nuclear & Others)

STANDARD NO.	TITLE
ANSI/ASME B88.2-74	Bench Calibration of Tank Level Gaging Tapes and Sounding Rules, Procedure for
ANSI/IEEE C60.15-63	Methods of Testing Electron Tubes
ANSI/ASME MC88.1-72	A Guide for the Dynamic Calibration of Pressure Transducers
ANSI/ISA MC96.1-75	Temperature Measurement Thermocouples
ASME PTC19.2-64	Pressure Measurement
ASME PTC19.3-74	Temperature Measurement Instruments & Apparatus Part 3
ASME PTC19.5-71	Application Part II of Fluid Meters
ASME PTC19.6-55	Electric Measurements
ANSI N42.3-69 (IEEE 309-70)	Geiger-Müller Counters, Test Procedure for
IEEE 498-75	Requirements for the Calibration and Control of Measuring and Test Equipment in the Construction and Maintenance of Nuclear Power Generating Station
ANSI/IEEE N323-78	Radiation Protection Instrumentation Test and Calibration
ISA RP16.6-61	Tentative Recommended Practice for Methods and Equipment for Calibration of Variable Area Meters (Rotameters)
ANSI/ISA RP31.1-77	Recommended Practice for Specification, Installation, and Calibration of Turbine Flowmeters
ISA S37.3-70 (ANSI MC6.7-75)	Standard for Specifications and Tests for Strain Gage Pressure Transducers
ISA S37.5-71 (ANSI MC6.3-75)	Standard for Specifications and Tests for Strain Gage Linear Acceleration Transducers
ISA S37.6-75 (ANSI MC6.5-76)	Standard for Specifications and Tests of Potentiometric Pressure Transducers
ISA S37.8-75 (ANSI S37.8-77)	Standard for Specifications and Tests for Strain Gage Force Transducers
ISA S37.10-75 (ANSI MC6.4-75)	Specifications and Tests for Piezoelectric Pressure and Sound Pressure Transducers
ISA S37.12-77	Standard for Specifications and Tests for Potentiometric Displacement Transducers
UL 1244-78	Electrical and Electronic Measuring and Testing Equipment
RG 1.105	Instrument Spans and Setpoints

Table 35-7-5 lists those standards and regulatory guides that address surveillance testing of instrument-and-control equipment.

TABLE 35-7-5
SURVEILLANCE TESTING STANDARDS

STANDARD NO.	TITLE
ANSI MC4.1-75 (ISA 526-68)	Process Control Instrumentation, Dynamic Response Testing of
IEEE 338-77	Periodic Testing of Nuclear Power Generating Station Safety Systems, Standard Criteria for the
RG1.22	Periodic Testing of Protection System Actuation Functions
RG1.118	Periodic Testing of Electrical Power & Protection Systems
BTP EICSB 24	Testing of Reactor Trip System and Engineered Safety Feature Actuation System Sensor Response Times

QA/QC VERIFICATION

Quality assurance (QA) and quality control (QC) were defined and described in Course 14, "Introduction to Quality Assurance/Quality Control." Module 35-6 briefly described how QC interfaces with preventive maintenance in order to enhance reliability/availability/ of systems and components.

In much the same manner, QA/QC interfaces in the design, installation, and maintenance/testing aspects of instrument engineering. Proper instrument engineering can develop instrument reliability without QA/QC verification, but the probability of achieving reliability is greater with QA/QC verification.

Quality assurance encourages the need for special controls, procedures, adequate M & TE, tools, skills, and training to attain the required quality. Quality control then encourages the need for verification of quality by inspection and testing. Since quality breeds reliability, QA/QC encouragement enhances instrument reliability in all phases of instrument engineering.

An example of quality-assurance requirements that affects instrument-and-control equipment used in Class 1E applications at a nuclear power plant is the Nuclear Regulatory Commission's Rules and Regulations, Title 10, Part 50, Appendix B — "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." Section XII, "Control of Measuring and Test Equipment," of this document sets forth the requirement that measures be established to "assure that tools, gages, instruments, and other measuring and testing devices used in activities affecting quality are properly controlled, calibrated, and adjusted at specified periods to maintain accuracy within necessary limits." This criterion establishes the requirement of maintaining quality in M & TE used in design (for instrument qualification testing), installation (for receipt inspection of instruments), and maintenance/testing (for PM, calibration and surveillance testing of instruments) so as not to hamper the quality established in Class 1E instruments. This criterion also applies to other equipment and systems.

Table 35-7-6 lists those QA/QC documents, standards, and regulatory guides that establish criteria for instrument quality and that, therefore, aid in attaining instrument reliability.

TABLE 35-7-6

QA/QC STANDARDS

STANDARD NO.	TITLE
ANSI/ASME N45.2-77	Quality Assurance Program Requirements for Nuclear Facilities
RG1.30	Quality Assurance Requirements for the Installation, Inspection, and Testing of Instrumentation and Electric Equipment
10CFR50, Appendix B	Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants

EXERCISES

1. List the three phases of instrument engineering, and explain how measures in each contribute to instrument reliability.
2. List the sources used to develop instrument installation procedures.
3. Explain how maintenance of quality in M & TE affects instrument reliability.

4. Explain how a "qualified" instrument can be considered a reliable instrument.
5. Describe how QA/QC verification encourages development of instrument reliability.

MATERIALS

1. Instruments:
    - Electronic pressure transmitter.
    - Resistance temperature detector.
    - Turbine flowmeter.
2. Measuring and Test Equipment:
    - As specified by the manufacturer's manuals for each instrument listed.

PROCEDURES

1. Calibrate the instruments listed in Materials section according to the manufacturer's recommended procedures, using the M & TE specified.
2. Use Data Table 35-7-1 for all instrument calibrations. Show all pertinent information.

DATA TABLES

DATA TABLE 35-7-1

Tag No. ________________ Description ________________________________

Location __________________ Safety/QA Class _______ Cal Freq __________

Manufacturer _________________ Model __________ Serial No. ____________

System _____________________ System Draw _____________________________

Input _______________ Output _______________ Alm Loc ________________

Trip 1 ______________ Prop Band ____________ Gain ___________________

Reset 1 _____________ Bias ___________________

Trip 2 ______________ Reset ________________ Lead ___________________

Reset 2 _____________ Rate _________________ Lag ____________________

Related Component Tag Nos. ____

Setting Ref ____

Maint. Procedure ______________________ Tech Man ______________________

Surv. Test Procedure _______________ Clearance No. ______ RWP No. ______

Remarks ____

Prepared by _____________ Date _____ Approved by ____________ Date _____

Purpose of Cal: Initial _____ Scheduled _____ MAR No. _____ Other______

Measuring & Test Equipment

Tag No.	Manufacturer & Model	Cal Due

Input	Desired Output	Tol.	Actual Output Precal Postcal	Remarks

Performed by _________ Date _______ Approved by _________ Date _________
Manhours ________________________

REFERENCE MATERIALS

Benedict, Robert P. Fundamentals of Temperature, Pressure, and Flow Measurements. 2nd ed. New York: John Wiley & Sons, 1977.

Electrical and Instrument Installation - Specification 2323-ES-100. Rev. 0. New York: Gibbs & Hill Inc., 1977.

Information Handling Services, VSMF - Industry Standards. Issue 8-4. Englewood, Colorado: Information Handling Services, 1979.

Morrod, L.C. Editor, Maintenance Engineering Handbook. 2nd ed. New York: McGraw-Hill Book Company, 1966.

Texas Utilities Generating Company. Final Safety Analysis Report - Comanche Peak Steam Electric Station.

APPENDIX A
QUALIFICATION PROGRAM
RTO AND THERMOCOUPLE ASSEMBLIES

1.0 SCOPE

The purpose of this document is to record the IEEE-323-74 Qualification performed on RTD and Thermocouple Assemblies purchased for Purchaser's Station Units 1 & 2.

2.0 APPLICABLE DOCUMENTS

2.1 Purchaser's Specifications

2323-MS-622	Design Specification for Testwells, RTD and Thermocouple Assemblies.
2323-SS-20	Seismic Criteria

2.2 Supplier's Specifications

Dwg. 2323-9028	RTD Assembly
Dwg. 2323-9033	RTD Assembly
Dwg. 2310-9029	Thermocouple Assembly
Dwg. 2026-9030	Thermowell
Dwg. 2026-9031	Thermowell
Dwg. N-30015	Nuclear Thermowell
Dwg. N-30016	Nuclear Thermowell
IPS-263	IEEE-323-1974 Qualification Procedure
IPS-265	Factory Test Procedures

2.3 Standards

ASME Boiler & Pressure Vessel Code — 1974 Edition, Winter 1975 Addenda

IEEE-323-1974	IEEE standard for qualifying Class 1E equipment for nuclear power generating stations.
IEEE-344-75	Guide for Seismic Qualification of Class 1 Electric Equipment for nuclear power generating stations.

3.0 CLASS 1E EQUIPMENT BEING QUALIFIED

The actual equipment being qualified are the following RTD assemblies:

Tag Nos.	
1-TE-5400, 5401, 5402, 5403, 5404	2323-9033-01, Rev. D
1-TE-4718, 4719, 4720, 4721, 4722, 4723	2323-9028-03, Rev. D
1-TE-4793	2323-9028-04, Rev. D
1-TE-4557, 4559, 4561, 4563	2323-9028-08, Rev. D
2-TE-5400, 5401, 5402, 5403, 5404	2323-9033-01, Rev. D
2-TE-4718, 4719, 4720, 4721, 4722, 4723	2323-9028-03, Rev. D
2-TE-4793	2323-9028-04, Rev. D
2-TE-4557, 4559, 4561, 4563	2323-9028-08, Rev. D

4.0 ADDITIONAL EQUIPMENT QUALIFICATION

4.1 In addition to the actual qualified equipment listed in Paragraph 3.0, it is the intent of this qualification report to qualify thermocouple assemblies of similar design to subject RTD assemblies. Two thermocouple assemblies were included in the testing in order to prove their capability to perform as Class 1E equipment.

4.2 It is also the intent of this report to show that Seismic Category 1 Thermowells provided meet the seismic design criteria Specification 2323-SS-20.

5.0 EQUIPMENT PERFORMANCE SPECIFICATIONS

5.1 RTD Assemblies

5.1.1 Accuracy shall be the greater of ±1°F or .5% of the reading.

5.1.2 Insulation resistance of any lead to sheath shall be 100 megohms minimum at 100V DC at room temperature.

6.0 SUMMARY

6.1 The results and analysis of all subject testing will demonstrate the capability of subject prototype RTD and Thermocouple assemblies to perform their required functions as Class 1E equipment. In addition, equipment of similar design, but different thermowell insertion lengths between the range illustrated by subject prototypes, could be considered as meeting IEEE-323-74 qualification requirements due to similarity.

6.2 The thermowell portion of suitable prototypes will be qualified to testing including Seismic simulation testing with no impairment to function by successful hydrostatic testing following subject type testing. This will prove the capability of all seismic Category 1 thermowells to meet their design requirements.

7.0 QUALIFIED LIFE

7.1 Subject testing is intended to simulate the range and extent of environmental conditions that the RTD and thermocouple assemblies would be subjected to during a 40-year lifetime. The test results will show that the prototype assemblies will continue to function as required for Class 1E equipment after all simulated testing was concluded.

7.2 In order to assure continued performance throughout their installed lifetime, we recommend that regular maintenance be carried out as listed in 7.2.1.

7.2.1 The following maintenance checks/operations are recommended at the intervals shown, in order to assure proper operation of subject Class 1E equipment:

A. Inspect connections at terminal block for good circuit continuity every 12 months.

B. Examine T8 termination head cover and gasket to determine that it is tightened to prevent ingress of outside contamination every 12 months.

C. Calibrate RTD probes at ice point every 48 months to determine that the resistance at ice point (32°F) has not drifted.

APPENDIX B

FLUKE 8600A DIGITAL MULTIMETER CALIBRATION

PURCHASER'S STEAM ELECTRIC STATION
INSTRUMENT & CONTROL MANUAL

FLUKE 8600A DIGITAL MULTIMETER CALIBRATION

Procedure No. INC-601
Revision No. 0

SUBMITTED BY: ____________________ DATE: __________
INSTRUMENT & CONTROL ENGINEER

APPROVED BY: ____________________ DATE: __________
SES GENERAL SUPERINTENDENT

PSES Instrument & Control Manual	ISSUE DATE	PROCEDURE NO. INC-601
Fluke 8600A Digital Multimeter Calibration	REVISION NO. 0	PAGE 2 OF 4

1.0 Purpose

The purpose of this procedure is to establish the calibration sequence for Fluke 8600A Digital Multimeters and to meet the calibration procedural requirements of the I & C Measuring and Test Equipment Program.

2.0 Applicability

This procedure applies to the Fluke 8600A Digital Multimeters listed on Attachment 1. This procedure becomes effective when issued.

3.0 Definitons

None

4.0 Instructions

4.1 Working Documents

4.1.1 Procedure INC-102, "I & C Measuring and Test Equipment Program".

4.1.2 Fluke 8600A Digital Multimeter Instruction Manual, Part No. 391409; January 1977.

4.2 Prerequisites

None

4.3 Precautions, Limitations and Special Conditions

4.3.1 Use only nonmetallic adjustment tools.

PSES Instrument & Control Manual	ISSUE DATE	PROCEDURE NO. INC-601
Fluke 8600A Digital Multimeter Calibration	REVISION NO. 0	PAGE 3 OF 4

4.3.2 Remove any applied voltage from the 8600A input terminals before starting the ohms calibration or current calibration.

4.4 M & TE/Tool List

4.4.1 As specified on the applicable Measuring and Test Equipment Data Sheet, Form INC-102-1, for the multimeter to be calibrated.

4.5 Preparation

4.5.1 Obtain the applicable Measuring and Test Equipment Data Sheets, Form INC-102-1 and INC-102-1A, for the multimeter to be calibrated.

4.5.2 Prepare the reference standards referred to in Section 4.4 and the multimeter under test for the calibration.

4.6 Performance

4.6.1 Follow "Section 4 Maintenance", paragraphs 4-24 through 4-32, 4-20 and 4-21, as found in the Fluke Manual beginning on Page 4-3 and ending on Page 4-5.

4.7 Acceptance Criteria

4.7.1 Specified tolerances or allowable deviations must be met for a successful calibration. If any repairs are required, tolerances or deviations must be met for subsequent calibrations.

4.8 Post Instructions

4.8.1 Affix proper label to the multimeter and insure that the M & TE data sheet is properly filled out and signed in accordance with INC-102, "I & C Measuring and Test Equipment Program".

5.0 References

5.1 Procedure INC-102, "I & C Measuring and Test Equipment Program"

5.2 Fluke 8600A Digital Multimeter Instruction Manual, Part No. 391409; January 1977

5.3 Procedure STA-202, "Preparation, Review, Approval and Revision of Station Procedures"

6.0 Attachments

6.1 Attachment 1; "Fluke 8600A Digital Multimeters"

Attachment 1
Page 1 of 1
Procedure No. INC-601
Revision No. 0
Page 4 of 4

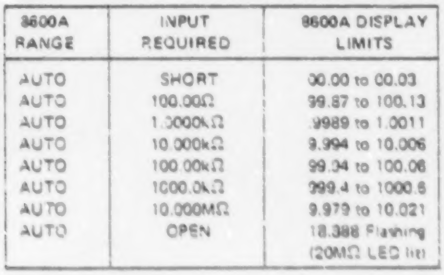
Fluke 8600A Digital Multimeters

	Tag. No.
1.	IC-1700
2.	IC-1701
3.	IC-1702
4.	IC-1703
5.	IC-1704
6.	IC-1705
7.	IC-1706
8.	IC-1707
9.	IC-1708
10.	IC-1709
11.	IC-1710

PORTION OF FLUKE MANUAL, SECTION 4

(NOTE: The Table numbers and paragraph numbers have been retained from the Fluke manual.)

Table 4-3. OHMS PERFORMANCE TEST

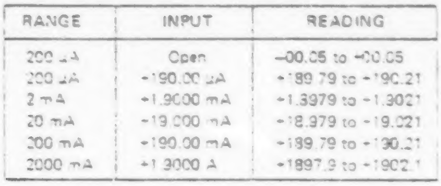


8600A RANGE	INPUT REQUIRED	8600A DISPLAY LIMITS
AUTO	SHORT	00.00 to 00.03
AUTO	100.00Ω	99.87 to 100.13
AUTO	1.0000kΩ	.9989 to 1.0011
AUTO	10.000kΩ	9.994 to 10.006
AUTO	100.00kΩ	99.94 to 100.06
AUTO	1000.0kΩ	999.4 to 1000.6
AUTO	10.000MΩ	9.979 to 10.021
AUTO	OPEN	18.388 Flashing (20MΩ LED lit)

4-20. DC Current Test

4-21. Using the dc current calibrator (check Table 4-1 for correct calibrator) sequentially apply the values of dc current indicated in Table 4-4 to the 8600A MA input terminals and select the ranges prescribed. The 8600A should display a reading within the indicated limits.

Table 4-4. DC CURRENT PERFORMANCE TEST



RANGE	INPUT	READING
200 µA	Open	−00.05 to +00.05
200 µA	+190.00 µA	+189.79 to +190.21
2 mA	+1.9000 mA	+1.8979 to +1.9021
20 mA	+19.000 mA	+18.979 to +19.021
200 mA	+190.00 mA	+189.79 to +190.21
2000 mA	+1.9000 A	+1897.9 to +1902.1

NOTE!

Because the current measurements of ac and dc are made using the same shunt resistors, a check of ac current is not made.

4-22. AC Voltage Test

4-23. Using the ac voltage calibrator, apply the ac voltages indicated in Table 4-5 to the 8600A V-Ω input terminals and select the ranges prescribed. The 8600A should display a reading within the indicated limits.

4-24. CALIBRATION

4-25. Introduction

4-26. The 8600A should be calibrated every 6 months or whenever repairs have been made, to insure the instrument continues to operate at its rated accuracy. After calibration is completed, the DC current performance test, paragraph 4-20 should be run through to verify the functioning and accuracy of the current dividers. The calibration should be performed under the following environmental conditions; ambient temperature of 23°C±5°C and a relative humidity of less than 80%. Refer to Table 4-1 for the recommended test equipment. Calibration adjustment locations are pictured in Figure 4-1. Perform the following preliminary steps before calibrating the instrument.

a. Remove the instrument from the case.

b. Connect the 8600A to the appropriate (115V ac of 230V ac) line power.

c. Turn the instrument on and allow it to warm-up for a minimum of 15 minutes.

d. Insure that the ac and dc calibrators are up to their normal operating temperatures.

NOTE!

Use only non-metalic adjustment tools.

Table 4-5. ACT PERFORMANCE TEST

8600A RANGE	INPUT REQUIRED	FRE-QUENCY Hz	8600A DISPLAY LIMITS
200 mV	190.00 mV	70 kHz	188.05 to 191.95 mV
200 mV	190.00 mV	500 Hz	189.46 to 190.54 mV
200 mV	39.00 mV	30 kHz	38.60 to 39.40 mV
2 V	1.9000 V	500 Hz	1.8959 to 1.9041 V
2 V	.9000 V	500 Hz	.8979 to .9021 V
2 V	1.9000 V	50 kHz	1.8900 to 1.9100 V
2 V	1.9000 V	100 kHz	1.8800 to 1.9200 V
2 V	1.0000 V	30 Hz	.9945 to 1.0055 V
20 V	19.000 V	500 Hz	18.959 to 19.041 V
20 V	19.000 V	70 kHz	18.800 to 19.200 V
200 V	190.00 V	500 Hz	189.59 to 190.41 V
200 V	100.00 V	30 kHz	99.45 to 100.55 V
1200 V	1000.0 V	500 Hz	996.9 to 1003.1 V
1200 V	1000.0 V	20 kHz	994.0 to 1006.0 V

4-27. DC Volts Calibration

4-28. The calibration procedure for the DCV FUNCTION of the 8600A is presented in Table 4-6. Use the recommended dc voltage calibrator (see Table 4-1) to apply the prescribed dc voltages to the V-Ω INPUT terminals and, where required, make the adjustments to meet the specified display limits.

Table 4-6. DC VOLTS CALIBRATION PROCEDURE

STEP	8600A RANGE	INPUT REQUIRED	ADJUSTMENT	8600A DISPLAY LIMITS
1	Select the VDC FUNCTION switch on the front panel.			
2	200mV	Short	none	−00.01 to +00.01
3	200mV	1MΩ*	C24	−00.01 to +00.01
4	200mV	+.19V	none	note display reading
5	200mV	−.19V	C30	within 1 digit of step 4 display
6	(Repeat steps 3, 4, and 5 until each step is within limits)			
7	20V	open	none	±00.00 to +00.01
8	2V	+1.9000V	R57	+1.8999 to +1.9001
9	2V	−1.9000V	R57	−1.8999 to −1.9001
10	(Repeat steps 8 and 9 until both are within limits)			
11	2V	+0.9000V	none	+0.8999 to +0.9001
12	200mV	+190.00mV	none	+189.95 to +190.05**
13	200mV	−190.00mV	none	−189.95 to −190.05**
14	20V	+19.000V	R4	+18.999 to +19.001
15	20V	−19.000V	R4	−18.999 to −19.001
16	(Repeat steps 14 and 15 until both are within limits)			
17	200V	+190.00V	R6	+189.99 to +190.01
18	1200V	+1000.0V	R8	+999.9 to +1000.1

* Place a 1MΩ resistor across the V-Ω INPUT.

** 200mV LED on the display should be on.

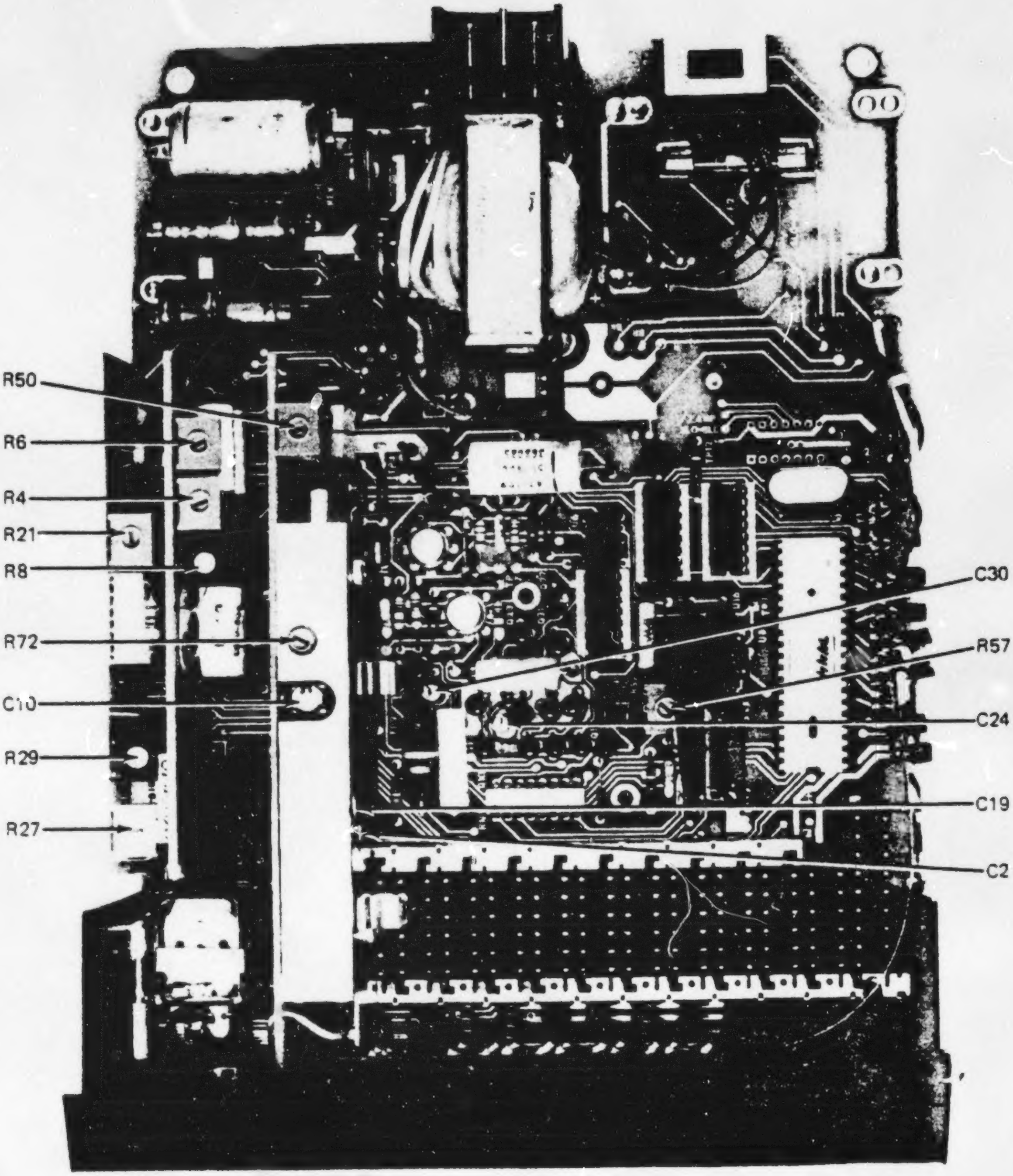

R50
R6
R4
R21
R8
R72
C10
R29
R27
C30
R57
C24
C19
C2

Figure 4-1. Calibration adjustment locations.

4-29. Ohms Calibration

4-30. The calibration procedure for the KΩ function of the 8600A is presented in Table 4-7. Use the recommended resistor decade (see Table 4-1) to apply the prescribed resistances to the VΩ INPUT terminals and where required, make the adjustments to meet the specified display limits.

CAUTION!

> Remove any applied voltage from the 8600A input terminals before starting the Ohms Calibration.

4-31. AC Volts Calibration

4-32. The calibration procedure for the ACV FUNCTION of the 8600A is presented in Table 4-8. Use the recommended ac voltage calibrator (see Table 4-1) to apply the prescribed ac voltages at the indicated frequencies to the VΩ INPUT terminals and, where required, make the adjustments to meet the specified display limits.

4-33. TROUBLESHOOTING

4-34. The following information is provided to assist in locating malfunctions in the 8600A. It is recommended that the theory of operation in Section 3 be read completely before attempting to troubleshoot the instrument.

Table 4-7. OHMS CALIBRATION PROCEDURE

STEP	8600A RANGE	INPUT REQUIRED	ADJUSTMENT	8600A DISPLAY LIMITS
1	Depress the KΩ FUNCTION switch on the front panel.			
2	200	Short	none	0.00 to 00.02
3	2000kΩ	1000.0kΩ	R21	999.9 to 1000.1
4	2	1.0000kΩ	R27	9999 to 1.0001
5	20MΩ	10.000MΩ	R29	9.997 to 10.003MΩ

TEST

1. Define the following terms:

   Reliability.

   Quality.

   Standard.

   Regulatory Guide.

   Class 1E.

2. Explain the preinstallation instrument application design criteria for both nonnuclear and nuclear utilization. (Refer to Tables 35-7-1 and 35-7-2.)

3. What is preinstallation verification? Why is it important?

4. Write a procedure for the installation and checks of a simple electronic pressure transmitter.

5. What is the purpose of calibration?

6. Describe and list the major electrical codes and standards for power plant instrumentation, and explain where they apply.

7. How does quality-assurance/quality-control verification interface in all aspects of instrumentation reliability?

NUCLEAR TECHNOLOGY

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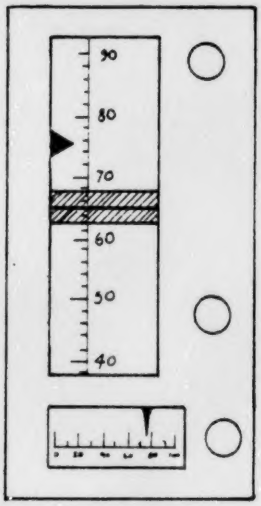
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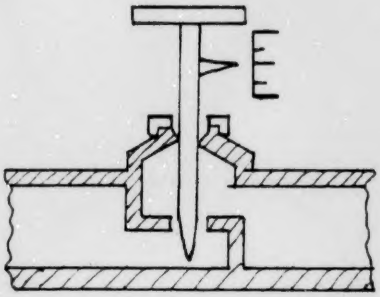

SYSTEMS AND COMPONENTS

COURSE 35

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

NUCLEAR TECHNOLOGY SERIES

INDEX

for

COURSE 35, POWER PLANT ELECTRICAL SYSTEMS AND COMPONENTS (SEVEN MODULES)

NOTE: Each module in this Course is numbered separately, and the page numbers begin with page 1 in each module. Therefore, this Index lists for each entry the module number (underlined), followed by a comma and the page number. Figures and tables are listed by their numbers, followed by the module and page number in parentheses. A Master Index is available in a separate volume. This general index merges all index entries from the 35 Nuclear Courses. It is a valuable research tool, with which the student or researcher can locate all the references to any subject within the 35 Courses.

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